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NOTES IN PSYCHOLOGY

on lectures supplementary to

JAMES' PSYCHOLOGY

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JAMES' PSYCHOLOGY

by

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PREFATORY NOTE

The presentation to large classes in a limited period of a survey of topics in Psychology most important for introductory study requires all the pedagogical aids that can be made available. The instructor must select his material, bringing to the teaching an individual emphasis, and inevitably supplementing the text in the process. The generous use of demonstrations and charts and diagrams within the lecture hour makes large draughts upon the student's attention and interferes with his notes. The present notes are the result of these conditions. The problems of Sense-Perception are considered the standard ones for the beginning student; a comprehension of principles is regarded as fundamental. It seems better to carry a few problems to a fair degree of completeness than to attempt too broad a survey. Moreover, as these notes are supplementary to James' Psychology, they must be considered along with the text, to restore the proper perspective. Points satisfactorily covered by the text receive no comment or restatement. It has been found impracticable to include in lectures (twice a week for one semester) much of the material of the latter half of the text. The notes will be used by the author in an introductory manual in preparation, the copyright of which is held by Henry Holt & Co.

CHAPTER I.

INTRODUCTORY.

Topic I. **The Nature of Psychology.** Psychology, as the science of mental functions, studies the processes that bring the individual into relation with his environment. Environment embraces the physical world, which contains various forms of energy, and the several biological factors which form the conditions of life.

A special relation obtains between the mind and the body. The nervous system represents the physiological basis of mental functions. The principle that physiological states condition mental states is illustrated by the effect of bodily injuries, and by the action of drugs, both of which show very decided changes of mental state, such as unconsciousness, lack of motor control, emotional exhilaration or depression, hallucinations, impairment of memory, etc. The same principle of relation between mental states and fluctuations in the condition of the nervous system is shown in detail in the minuter changes of condition. These are illustrated by the effects of fatigue, of hunger, of difference between morning and evening, of influences of the weather, of digestion, and of a score of the more delicate variations which make it safe to assume that to every mental state there corresponds some kind of a physiological state of the nervous system.

CHAPTER II.

SENSE-PERCEPTION.

Topic II. **General Characteristics of Sensation.**

Sensation represents the simplest mental process that participates in the mental life. Sensations are thus the first things in consciousness. It is possible to distinguish the bare effect on the organism of being exposed to a stimulus, and to call this the sense-impression. The stimulus is some form of energy in the outer world; and the sense-organ represents the adaptation of a cell to receive this form of energy. Accordingly the sum total of our sensations is limited by the variety of forms of energy which we have senses to receive. All such adaptations are special, and again are limited in range. Thus: the cells of the retina respond to light-vibrations, and the cells of the end-organ in the ear respond to air-vibrations. Having these specialized responsive organs, we see colors and hear sounds. But the range of color which we see is limited by the structure of these cells. We know that there are vibrations below the red and beyond the violet which are just the same kind of vibrations, but which we do not *see*. Similarly we can see, but not hear as sound, the vibrations of a stick which is not vibrating rapidly enough to produce an audible tone; and we can show that when vibrations get more rapid than the upper limit of hearing, there is a rush of air, but no musical tone. Once more, we know that there are forms of physical energy, like magnet-

ism, for which we have no sense-organs whatever; we cannot *feel* the presence of a magnetic field. It may be assumed that the kind and range of our senses represents the maximum utility of sensory functions.

Topic III. Body-informing and World-informing Use of the Senses. The sensations give information regarding conditions of the body for use and protection, particularly as pain and pleasure; and this factor remains even when it becomes secondary. The chief development of the senses is towards giving information of the outside world; and this use may be called *intellectual*. It results in the making of distinctions. The accuracy of the sense, or its delicacy, is measured by the smallness of the distinctions which it makes. These distinctions are both in matters of degree and of kind, or quality. What we really distinguish are *qualities of objects*, but the information may be reduced by psychology to types of qualities, such as color and form, and again size and distance for vision; or loud and low, high and deep tones for hearing; heavy and light, hot and cold, for touch; sour and sweet for taste; and so on. In all these distinctions the factor of use, or pain and pleasure as protective, remains, but in many cases is slight, giving way to distinction.

Topic IV. Sensation and Action. The use of distinctions is to regulate conduct. Situations must be distinguished so that they may be appropriately reacted to. In considering distinctions, it is important to think of the situations as simply as possible, and as they commonly occur in nature. Distinctions are directed to objects. There is a strong tendency to refer all sensations outward and in terms of meaning, to perceive objects and disregard sense-impres-

sions. As a consequence, for the higher senses we are very little aware of sense-impressions, and at once infer the presence and nature of the objects which cause them. Hence, we often fail to realize the basis in sensation of the result which we perceive or infer. For example, we know that we distinguish the direction of sounds, but need experiment to prove that the basis of this distinction is a difference in intensity in the two ears. Again, we are very likely to infer that a light that is growing brighter is nearer. We are not usually aware that brightness is the basis of our inference of nearness. What we seem to perceive are objects or situations in accordance with their most familiar appearance; the basis of such perception are simple sensible qualities. Out of these sensations we at once build up objects. We seem to perceive them as a whole, and overlook the steps involved.

Topic V. **Intensity.** Among the qualities in common to all sensation is that of intensity, which is the simple distinction of more or less. Intensity has the advantage of being easily studied. Changes in degree, such as that of a weight growing heavier, of a light growing brighter, of a sound growing louder, are relatively simple distinctions. It is true that the sensation may change slightly in quality as the weight grows heavier or the sound louder or the light brighter; but we can distinguish the predominant element of change of degree, and can usually distinguish this from a qualitative change, such as that the tone becomes higher, or the light more bluish, or the pressure duller or sharper. Changes in intensity have been minutely studied. One of the important results is that relative differences are shown to be more important than absolute ones. This is again in accord

with natural use, and indicates that there is a standard of utility in making distinctions. It may be illustrated in terms of weight by saying that one ounce added to four or five ounces will be much more marked than one ounce added to twenty or twenty-five ounces. When this principle is made accurate, it would read that a change of one ounce in a pound would be about as perceptible as a change of two ounces in two pounds. Just how far the law holds will be seen later. The principle is clear that the perceptibility of the difference stands in very definite relation to the total impression. It is also true that sudden changes are more perceptible than gradual ones. We do not observe that a room is growing warmer as we sit in it, but someone coming from outdoors notices that it is too hot. Another general factor is contrast, which means that the present condition of the organ affects the impression, and also that one impression affects another. Such contrast is an illustration of the fact that a sensation is relative, and its effect depends upon the total impression. Thus, if one hand be placed in hot water and the other in cold, and both transferred to the same dish of lukewarm water, it will seem cold to the hand that has been in hot water, and warm to the one that has been in cold water. Similarly, colors will have a very different effect when placed upon background or another. There are, however, many varieties of contrast to be noticed later.

(It should be noted that the general subject of this chapter is a survey of the qualities which many or all sensations have in common, and of the general processes involved in sensation.)

CHAPTER III.

VISION.

Topic VI. **The Organ of Vision.** The study of vision is best adapted to illustrate the principles of sense-perceptions. It makes it possible to trace step by step all the processes from the physical stimulus to the most complex sense-perceptions. We must consider that the organ of vision, which is the eye, is primarily an organ for color-perception, and again an organ for the perception of form. These two orders of perception are concentrated in the retina, and specifically in a single layer of the retina known as the rod-and-cane layers. These form the end-organs of vision, and are probably at once the end-organs for color and for form. It will be altogether best to describe the structure and functions of the eye in terms of form-perception.

Topic VII. **The Formation of the Image:** (a) **Structure of the Eye.** All vision depends upon the formation of an image on the retina. Our first inquiry is as to the structure of the eye, particularly with reference to the parts that lead to the formation of the image, and the method by which each part contributes to the result.

The eye is a sphere a little deeper than broad, and flattened in front, and is about seven-eighths of an inch in diameter. It consists of three coats: the outer or sclerotic, which in front becomes vaulted and transparent, forming the cornea; the middle coat, called

the choroid in back, which in front becomes flattened as the iris, with the opening in it, the pupil. Inside is the third coat, the retina alone, which stops at the margin of the ring formed by the junction at once of the retina, the choroid-and-iris, and the sclerotic-and-cornea. In addition the solid or liquid contents of the eye appear first in the vitreous humor, quite the largest in mass, filling all the space between the retina and the iris, except that there is a depression in its anterior surface in which rests the second important solid body, the lens. The space, flat in back and vaulted in front, between the iris and the choroid, is filled with a watery substance and is called the aqueous humor. In addition there are within the eye various blood-vessels, particularly in the choroid, bringing its rich blood-supply, the ligaments which hold the lens in place and which are attached to the two important ciliary muscles through the action of which the lens contracts. The eyeball as a whole is harnessed by a set of six muscles, four of which are straight, one above, one below, one external, and one internal, and two of which are oblique.

In terms of function the sclerotic coat serves as the solid wall keeping the eye in shape, and also as the points of attachment for the muscles. The cornea is of a similar structure as the sclerotic, but transparent to permit the passage of light. The lens has the important function of breaking or refracting the line of light so that the image falls *on* the retina, and not in *front* or in *back* of it, and that as well for *near*, for *middle*, or for *far* distances—this process being known as accommodation. The iris contains the mechanism of light adjustment, the pupil becoming very small in strong light and expanding in weaker light. Con-

sidered generally, the eye may be regarded as the retina, which in turn is the expansion of the optic nerve, and a set of accessory mechanisms for regulating the light and forming the image, of which the chief are the lens and the iris.

Topic VIII. The Formation of the Image. (b)
Processes and Conditions. While we see with nearly the entire extent of the retina, a fundamentally important condition of accurate vision is that the image shall fall on the fovea. Human vision is peculiarly foveal vision, which means that directly in the center of the retina there is a depression, or fovea, in which vision is concentrated. A ray of light entering horizontally through the exact center of the pupil, would reach the center of the fovea. The structure of the retina shows that the visual elements, or rods and cones, are most closely concentrated at this point, in extent, a space of about one-eighth of an inch. Furthermore, at this point there are cones alone, and these closely crowded. Towards the margins of the fovea there is about one cone to a circle of rods surrounding it; and in the areas farther away from the fovea in all directions the proportions of cones to rods diminish, and both elements are more and more separated by other tissue. This distribution proves that the rod-and-cone layer is the layer of visual perception, and that the cone is more intimately connected with the visual process than the rod. (For structure of retinal layers, see text.) A complementary proof is furnished by the existence of the blind spot, which is the entrance of the optic nerve. At this point, a little to the inside of the fovea, the fibres of this nerve pierce through all the coats of the eye. The retina may be pictured as the spread-out ends of these

fibres. Naturally, at this point there are no rods and cones, and hence no vision. (For experiment proving the blind spot, see text.)

Topic IX. General Conditions of Vision. The conditions under which the eyes are used may be divided into "vision with the eye at rest" and "vision with the eye in motion;" again into "vision with one eye" (monocular) and "vision with two eyes" (binocular). For purposes of exposition it is well to accept as the standard "vision with one eye at rest." This affords the simplest conditions. As a matter of experience, the use of the two eyes jointly and in constant motion is the dominant method. The largest share of information, as well as the normal use of the eyes, involves *binocular* vision and constantly *moving* vision. Conformably to the general discussion, we may call "vision with the eyes at rest," passive and "with the eyes in motion" active. It will be recalled that we have but two types of sensation: (1) the stimulation of a specialized sense-organ, or (2) the feeling accompanying the contraction of muscle. The sensibility of the retina represents the former type; the contraction of the muscles in moving the eye, the latter. *Active vision combines* the two, and refers to the total sum of information which we get from the retinal images, as well as from the feeling of ocular movement.

Remembering the practical and theoretical importance of these four modes of using the eye or eyes, we ask the typical question for each sense, namely, "What are the kinds of information which the sense affords, and how do we get them?" Such analysis must be complete, must yield simple and distinctive types of information. For vision the analysis yields the following result:

A. The Light-and-Color Sense. B. Space-Perception. These two are doubtless related to quite different phases of the visual process. The colors and the shapes of objects are seen combined; but the color factor and the space factor are readily separated mentally. We distinguish Light and Color, and subdivide the qualities of space-perception as follows:

- | | |
|---------------|-----------|
| I. Direction. | |
| II. Form. | A. Light. |
| III. Size. | also |
| IV. Distance. | B. Color. |
| V. Solidity. | |
| VI. Movement. | |

What this analysis means is that the visual difference between one object and another may be reduced to differences, first, of color (as blue or red), and brightness (as light or dark); and secondly, to differences in space relations, of directions (as right or left, up or down), of form (as round, square, hexagonal, or again leaf-shaped, heart-shaped, etc.), of size (as large and small), of distance (as far and near), of solidity (as flat or solid, or variations in depth in the third dimension), and finally of motion (as moving or at rest). This analysis might be carried farther, resulting in fewer factors at the expense of convenience. This answers the question, "What kind of information is thus given?" The answer to the method by which we receive them involves the separate treatment of each problem.

It is further true that we may obtain these space-perceptions from the eye at rest or in motion, from the single eye or the two eyes. It is further the case that *no new perception* is added by the more elaborate

visual processes; and it is likewise true that (with the partial exception of solidity) there is no form of information which is not obtainable through the single eye at rest. The difference is largely one of convenience, extent, and variety of spacial experience; but that means a great practical difference. It will be best to consider each of these factors of space-perception in terms of single vision with the eye at rest, and then observe the variations in the process due to the presence of binocular vision, and again of the movements of the eye.

Topic X. The Perception of Direction and Form. These perceptions result directly from the method of formation of the image. The perception of direction in the single eye at rest is determined by the position on the retina at which the image is formed. Owing to the inversion of the rays by the lens, the upper half of the retina corresponds to the lower field of vision, and the lower half of the retina to the upper field of vision; similarly whatever I see on the extreme right in space falls on the inner half of the right eye, and what is to my left in space falls on the outer half of the right eye; and again conversely, if I use the left eye alone. As all rays entering the eye cross at the nodal point, which is a little back of the center of the lens, it is easy to find the position on the retina of a point in space by simply connecting that point with the nodal point, and extending the line to the retina. Owing to this fixed relation, I come to associate definite regions in space with definite positions on the retina; and this association is never seriously interfered with by the fact that I use two eyes, and that the eyes are in constant motion. A convincing proof of this fixed association is obtained by closing the eyes and pres-

sing the little finger lightly against the eyeball on the inner (left) side of the right eye. This mechanical pressure will cause a dull illumination, which in turn will be referred to a region in space on the extreme right-hand side. It is thus easy to formulate the principle of direction. Objects above, like those on the ceiling, are associated with the lower part of the retina, and objects on the floor with the upper part of the retina, and so on. Direction is then due to the fixed association between position on the retina and position in space, the relation in turn determined by the inversion of the image under constant conditions.

The perception of form, or shape, is likewise determined by the formation of the image. The retinal image is a facsimile of the object seen. Its outline, or contours, will accordingly reproduce the outline or contours of the object, and this miniature will be accurate in light and shade, color, and form. The difference, then, between a square and a disk is in the *combination of stimulated points*. This convenient phrase summarizes the condition on which depends the perception of form. The accuracy of form-perception depends upon the accuracy of the mechanism of the eye in forming a sharp and distinct image. It has its limits in the power of the lens to focus for near, or in some eyes for distant objects; but given a clear image, the form-perception results. Here again, constant association through experience familiarizes and facilitates the rapid perception of distinctions of form.

It is difficult to arrange a test of the sense of direction alone, and not much easier that of form alone, since both are so commonly involved with other perceptions. For direction, one might arrange in a dark room that a single pin-point of light shall appear for

an instant, disappear, and then another reappear at a different place, and the subject be required to indicate the difference of direction between the first and the second points. For form, again, one might take a series of ellipses slightly changing the proportions of the two axes, and determine which is the more elliptical; or again, one might arrange very slight differences in irregular shapes, like inkblots, and determine how far changes could be detected. The test of the ellipses at once suggests that size, in the difference between the vertical and horizontal axes, would enter, and again that the difference between one curve and another is merely that of a difference in the arrangement of change of direction. Thus a straight line is a line that does not change its direction, and a circle is one that constantly changes its direction. None the less, direction and form, though commonly combined with other space-perceptions, are sufficiently distinct to be separately considered. Though expressible in terms of direction, form is a simple perception.

A special problem arises from the inversion of the image, and it might be supposed that to see an object erect with an inverted image requires explanation. Since, however, the whole process is a matter of association, it is just as easy to learn to associate the lower part of the retina with the upper part of the field of space as vice-versa. The demonstration given in the class showed that by means of casting a shadow on the retina, we can prove that an erect image (for the retina does not recognize the impression to be a shadow, and treats it like an image) would be projected and seen inverted.

Topic XI. The Perception of Size and Distance.
While the perceptions of form and direction depend

wholly upon the position and distribution of the retinal image, the perception of size depends upon it primarily but under the assumption that other relations are constant. It may, then, be said that, *other things being equal*, the size of the retinal image will be a sufficient clue to the size of the object. Of two objects at the *same* distance from the eye, the larger will throw an image upon the retina proportionately larger than the smaller one. It is, however, obvious that other things as a rule are *not* equal, and that primarily the one factor making distance and size relative judgments—indeed relative to one another—is the fact that size varies with distance and distance with size. We are thus compelled to speak of the apparent and the real size of an object.

The figures shown on the blackboard illustrate how a set of objects may all be of the same size, but at different distances from the eye, and accordingly have images of different sizes; or again that three objects of different sizes may be so adjusted in their distances from the eye that all three, the nearer, the middle, and the farther object, may have a retinal image of precisely the same size. In practice, accordingly, we can distinguish three types of problems: First, with objects at the same distance, to judge of their relative size. For this the size of the image is adequate. Second, for objects at a different distance but known or assumed to be of the same size, to judge of their relative distance. Such judgment of distance would in the one eye be accomplished by the mechanism of accommodation, as will be explained presently. Third, and most usual, objects at different distances and of different sizes, to be judged at once relatively as to their size and distance. This complex problem, involv-

ing many factors, is the one in which we gain great proficiency.

Returning to the first problem, there is little to add, since, the determination of the distance of an object being somehow accomplished, the judgment of size depends upon the size of the retinal image. However this is often so complicated by movements of the eye, by differences in shape and in direction, that it still remains true that the perception of size is as a rule not simple. The point will be considered again in connection with the movements of the eye.

The perception of distance independently of size depends upon the feeling of the set, or amount of contraction, of the ciliary muscle, which in turn sets the lens to give an accurate image upon the retina. We may call this briefly the process and the feeling of accommodation. It has its sensory counterpart in the blurredness of the image, which we disperse by changing the accommodation and thus sharpening the image. In a familiar space and within short range, say twenty feet, the shifting accommodations in order to produce clear images would sufficiently determine judgments of distance. Since both size and distance are relative and can be expressed in terms of changes of angle of vision, it follows that a much smaller change of distance at a nearer range will induce as much feeling of change as a considerably larger change of distance at a larger range. To move the finger away an inch or so at a distance of five or six inches involves far larger changes of accommodation, as well as of size of retinal image, than to move it an inch or two at a distance of twelve inches. But for every successive foot the difference in set (and in size of image) rapidly diminishes. It has been calculated that the

changes of accommodation substantially stop at twenty feet, and further that within this distance the reading distance of ten or twelve inches covers the largest changes of accommodation.

The combined problem of judging size and distance jointly is one that requires large experience to solve, and which under unfamiliar conditions we often fail to solve accurately. Experiments in the dark room show that the ordinary judgments of the distances of objects are complex, the judgment depending on their known size, on their relative position to one another, on the cutting off of images, on the way in which the objects catch and reflect the light, and on other details. It is only when these are eliminated that we get a clear notion of the power to judge distance and size by the combined processes of size of image and of accommodation. It may be added that the question as to which factor leads in the joint process, or which step is first taken, again depends upon circumstances, and possibly individual habit. Do we first judge the distance and then determine the size, or get the size and then determine the distance? The most generally correct answer is that we shift from one to the other, and by mutual adjustment clear up the size and distance together. In this process the eyes may readily be deceived, and illusions of judgment result. This problem will be further considered under "Binocular Vision."

Topic XII. The Perception of Solidity. The nature of this perception is easily defined, but the variety of its appearance complicates the problem. It refers to the third dimension of objects, as well as to the relation of the parts of an object in *depth*, thus including perspective. At the simplest, the distinction is

between a flat and a solid, and as illustrated between a disk and a hemisphere. Neglecting the matter of light and shade, and still considering vision with one eye at rest, the disk is distinguished from the hemisphere because all parts of the disk require the same accommodation, while to see the center of the hemisphere clearly requires a nearer accommodation than to see its edges clearly. If the hemisphere were a *hollow* half-ball, then focusing for the edges would require closer accommodation than for the center. Similarly for the skeleton pyramid as held with the larger square nearer, thus looking into the pyramid, or with the smaller square nearer, and looking down its sides, the retinal images of the single eye in the two cases may be precisely alike, yet the two appearances are instantly distinguished, and this again by the difference in the shiftings of accommodation. Such is the perception of solidity at its simplest.

Topic XIII. Vision with Two Eyes. The further consideration of solidity involves binocular vision. The first problem is the question of seeing singly with the two eyes. Clearly the images on the two retinæ as formed by a single object are related; and when the eyes are directed towards an object, the image thereof falls on the fovea of each eye at the same time. This process is called *fixation*, and is popularly called "looking" at an object. It is accomplished by a movement of the internal (or external) muscles.

Topic XIV. Movements of the Eyes. Of the six muscles attached to each eye, there are four straight muscles,—upper and lower, internal and external—and two oblique muscles, again upper and lower. The oblique muscles cooperate with the others, and give a torsional movement to the eyeball. The upper

straight muscle raises the eyeball, as in looking at the ceiling, and the lower straight muscle turns the eyeball downward, as in looking at the floor. The upper and lower muscles of the two eyes always work together, there being no power to raise one eye and lower the other, for the very good reason that this would not lead to single vision. When the two eyes turn to the right, it is done by a pull on the external muscle of the right eye and the internal muscle of the left eye; and when, conversely, the eyes turn to the left, it is done by a pull of the external muscle of the left eye and the internal muscle of the right eye. If the eyes move from a point on the floor to the left, and then roll obliquely to look at a point on the ceiling and to the right, and then again move back to the point on the floor, all six muscles of both eyes have been brought into play. Such general movements, by which objects in space are examined are called *movement of exploration*. In addition, the distinctive type of movement which consists of a pull on the two internal muscles when an object nearby is to be looked at is *convergence*, and the converse pull on the two external muscles when the fixation is transferred from a point nearby to a point far off, is called *divergence*. Instead of constantly referring to these movements as movements of convergence and divergence, they are often referred to as *movements of convergence*, or again, *convergence shiftings*. It thus appears that the internal and external muscles participate as well in movements of exploration, and that they alone have this additional power of being moved in a converse combination for convergence and divergence.

The conditions of single vision may be expressed by saying that an object in space will under normal

conditions be seen singly when the images thereof fall on the two foveae, or on points of the retina equidistant from the foveae and in the same direction. The word direction here needs no definition so far as up and down is concerned, since the eyes inevitably move up and down together; but as applied to horizontal movements the words "same direction" now mean that the points on the retinae must be in the same direction—either in both eyes to the right of the fovea or in both eyes to the left of the fovea. Observe that this means that a point internal of the fovea in the one eye corresponds to a point external of the fovea in the other eye, and vice versa. Such points are called *corresponding points*. The eyes have such large experience in moving together that they instantly and quite unconsciously assume the correct position to obtain single vision, the guiding clue being the clearing up of blurred images. It must still be said that movements of accommodation in each eye always accompany the convergence movements of the two eyes, so that the combined movement at once brings the image on the fovea of each eye and focuses that image sharply at that point.

Topic XV. Double Images. It might almost be said that under the conditions described, single vision will take place, and that under all other conditions we should see double. The fact that double images do not bother us, and indeed that we ignore them, is due to the constant movements of the eyes in convergence and divergence, which destroy or disperse double images as soon as formed. It takes some practice to learn not to move the eyes, and thus to attend to and see the double image. The simplest condition for observing them is at near range, holding the finger, F,

as the point of fixation, and some other point, P, as a pencil, as a point to be seen in indirect vision, both points in the horizontal plane. If the finger be held at about eight inches from the eye and the pencil at about double the distance, and the finger-nail be sharply fixated, two images of the pencil would appear, one to either side of the finger-nail. Conversely, if the finger be held at the further distance and the pencil at the nearer, again two images of the pencil would appear. These form the two chief conditions for the appearance of double images, which may be expressed as one by saying that the point of fixation is at a different distance from the eyes than the point of indirect vision. These two types of double images require opposite movements to destroy or dissipate them. For the first experiment, a movement of divergence, or spreading of the eyes apart, is necessary to transfer the fixation from finger to pencil—from F to P; and for the second a movement of convergence is necessary to transfer the fixation from finger to pencil—from F to P. Prepare a diagram of the experiment. In brief, then, we know that the finger is nearer than the pencil, or the pencil nearer than the finger, because of our feeling as to the kind of movement necessary to get rid of these double images. In practice they appear not so much as double images, which are distinct only when the points are nearby and separated, but as blurred images. Furthermore, observe that in the two experiments the double images of the pencil are spread farther apart when the pencil is near than when the pencil is far; and in addition if, when the pencil is near, you close the right eye, the opposite, or left, double image will disappear; or with the pencil farther away, the closing of the

right eye will momentarily make disappear the right-hand image. Prove this on the diagram.

Topic. XVI. Binocular Perception of Distance and Solidity. It thus appears that we have two processes for perceiving distance and solidity; accommodation in the single eye and convergence in the joint working of the two eyes. Experiments show that the convergence gives the more accurate judgment for all but very near distances, and the readiest judgment for all. While accommodation is pretty well equalized at twenty feet or so, convergent shiftings are still useful at forty feet, and possibly anywhere from forty to a hundred, or even two hundred feet. Obviously both changes are relative, as explained under accommodation. The point at which the two eyes are approximately parallel represents the limit of convergence. The perception of solidity in binocular vision involves another, and in principle the most important factor, namely the fact that the two images on the two eyes are slightly different. This factor is called *retinal dissimilarity*; and the stereoscope demonstrates the part that it plays in the perception of solidity.

Topic XVII. Stereoscopic Vision. The proof that retinal dissimilarity and convergence shiftings together furnish the perception of the three-dimensional world is given by the stereoscope, one of the most wonderful if simple instruments ever invented. The stereoscope is a synthetic instrument, which puts together the factors which analysis has found, and actually reconstructs the third dimension of space out of two-dimensional materials. The principle of the stereoscope is that of giving to each eye its own image, and furnishing a convenient method of combining the

two images. In the form in which it is popularly known, the stereoscopic photograph consists of two views of an object, taken a little distance apart, the distance corresponding nearly or accurately to the separation of the two eyes in the head. Thus the two pictures actually show how the two images on the two eyes would differ; and it will be observed that these differences may be extremely slight for all objects at a great or considerable distance from the camera, but that the differences increase decidedly for objects near by. Examining a stereoscopic photograph of the latter class, it is easy to make out that in the right and left pictures the views of objects in the foreground are more different than of objects in the background. These differences illustrate what is meant by retinal dissimilarity.

The simplest demonstration is afforded by diagrams, and best by outline figures without background. The truncated pyramid with the square base, which is the shape of the models shown in class, may serve at once to indicate the measure and distribution of retinal dissimilarity, and to show how the images may be combined in the stereoscope and actually produce the effect of solid reality. Any instrument that gives each eye its own image and combines them is a stereoscope; and several varieties of such instrument were demonstrated.

As to the relative parts played by retinal dissimilarity and by convergence shiftings, observation shows that the dissimilarity alone suggests solidity, and produces it for simple figures, but is completed and made far more realistic by the movements of convergence. Thus a stereoscopic view grows in depth as the eyes look at it, and often the moment of the ap-

pearance of intense solidity can actually be detected. This requires adjustment of the eyes and clearness of view. Hence the need of more accurate devices for persons whose eyes do not naturally work well together. Note clearly that the fully developed stereoscopic impression is not an imitation or a suggestion of reality, but an actual reproduction. What the eyes see in looking at a stereoscopic picture is precisely what they see in looking at reality.

Topic XVIII. Secondary Factors in Depth-Perception. At this stage a distinction must be made between the the primary factors of depth-perception and the secondary ones. The term primary always refers to information obtained through processes going on in the organ of perception—in this case, in the eye; and the term secondary refers to inferences from the observed relations of objects as modified by experience. For purposes of analysis the primary factors always dominate, but in practice the secondary factors may come to be the more important and reliable. The secondary factors of depth-perception relate to qualities of the objects and their distribution in space. They may be enumerated as (a) light and shade; (b) interposition of objects; (c) perspective; (d) familiarity. In addition there are others playing occasional and accidental parts. Light and shade is a very comprehensive clue of depth-perception, because most objects are opaque and cast shadows, and the differences of lighting indicate position in the third dimension of space. All these secondary factors are inferences, and suggest, rather than create the perception of solidity. That light and shade is an inference from the assumption that the direction of light is from above, the photograph of the turret shows.

Similarly, light and shade is so powerful that it always suggests and carries the conviction of solid objects. The interposition of objects refers to the principle that the nearer objects more or less obstruct the view of the more distant ones, or again that the forward portion of an object interrupts its more remote parts. This too was variously illustrated. Familiarity is a complex factor, and refers to the known relations of size and distance, as well as to position in space. The only method to show clearly the importance of this factor is by application to situations which are unfamiliar.

Topic XIX. Relative Place of Primary and Secondary Factors. A stereoscopic diagram of a simple geometrical figure dispenses with all such aids as light and shade, interposition of objects, perspective, and familiarity, and proves that the primary factors alone are sufficient to create the perception of solid objects. This demonstrates the adequacy of the primary factors, and that in principle they are sufficient to induce the result. Conversely, if we take two photographs side by side and combine them in the stereoscope, but have these photographs absolutely alike, then we shall have all of the secondary factors suggestive of solidity, or reenforcing the perception of solidity, but not the primary factors. At first sight a good photograph sufficiently suggests solidity, and the uninitiated might mistake such an effect as a true stereoscopic impression; but by comparing such a pair of photographs with a pair which show the stereoscopic differences, the enormous increase in vividness and realism of depth-perception by adding the primary to the secondary factors once more illustrates that the real depth-perception is stereoscopic—that is,

involves primary factors with or without the realistic aids of one or another of the secondary factors. It is clear that all art that deals with representations on surfaces, like photographs, engravings, paintings, and so forth, utilize only the secondary effect, and suggest solidity. The stereoscopic picture is accordingly in a class by itself. The art of painting is in this sense an illusion or suggestion.

As to the relative importance of the several factors, a few examples indicate how under different circumstances familiarity and perspective may be supplemented by the true stereoscopic effect. Differences of foreground and background may be suggested by the photographic perspective, but are decidedly reinforced by the stereoscopic effect. Cases of unusual positions of the eye, involving complex interpretations, are also much better solved under true stereoscopic vision, as the examples shown illustrate.

Topic XX. The Stereoscopic Range. Retinal dissimilarity and convergence shiftings, as well as many of the secondary factors, depend for their effect upon the range at which the eyes are working. It is clear that in general the primary factors will be most decisive for near ranges; and that retinal dissimilarity, as well as convergence shiftings, will rapidly diminish with the increase in the distance of the object. Accordingly, it is the secondary factors that alone remain strongly operative at long distances. Thus in looking out of the window at a series of trees, which may be of all sorts of shapes and sizes and positions, I get some information of relative nearness and farness, particularly of the nearer group of trees, from retinal dissimilarity and convergence shiftings. I get this perception the more clearly when there is a striking

object in the foreground. But beyond a moderate range, my real information becomes of the secondary order—light and shade, notably, the interposition of objects, and perspective. That is why outdoor effects in stereoscopic vision need hardly be very stereoscopic, if they only give a clue by having an object in the foreground. We thus conclude that practically the secondary factors may in many views be more effective than the primary ones, though in principle the reverse relation holds.

A peculiar relation applies to the retinal dissimilarity of objects at close ranges and in the horizontal plane. If at this range objects were presented as they appear on the retina, the nearer object would look to us altogether too large. In other words, for very close objects we allow the known size to interfere with the actual image; and when confronted with the actual images of very close objects, they seem to us wholly out of perspective. Note that these grotesque out-of-perspective views actually correspond to the retinal images. It is the virtue of stereoscopic photographs that they can combine anything that the eyes can see, and these seemingly out-of-proportion views when stereoscopically combined show the correct relation.

Topic XXI. **The Perception of Color.** The perception of color offers an instructive contrast to space-perception in that the sensory element is so entirely dominant, and the factor of inference or secondary interpretation so entirely absent. While we do not know the precise process that goes on when color is perceived, and are quite ignorant of what process goes on in the eye when we see red which is different from some other process resulting in the perception of blue,

we are none the less warranted in assuming some distinctive impression of the rod-and-cone layer in the retina, and presumably some different stimulation of the constituent elements of each cone. Our knowledge of the physiology of color is thus most inadequate. Of the physical cause of the stimulus to which our eyes respond with the sensation of color, we know definitely that it is the rate of vibration of the light-carrying medium from 470 billion per second for the red to 722 billion for the violet. If a beam of light be broken up by passing it through a prism, the different degrees of refraction spread out the rays into its constituent wave-lengths, thus forming the spectrum. But the spectrum really represents the limit of responsiveness of the color-perceiving elements. There are of course vibrations of similar kind beyond the red and the violet, to which, however, our organs do not respond. As a consequence, our description of color sensations is largely psychological.

Topic XXII. Facts and Theories of Color-perception. A theory of color-perception must express the observed facts in an intelligible form, throw some light upon their relations, and if possible reduce the complex phenomena to a unified and simple set of relations. The importance and description of the facts may be modified in terms of the preferred theory. Of greatest importance are the following: 1. Color Range and Color Mixture. The normal range of color seems definitely fixed by the spectrum. The question as to how many color distinctions we can distinguish involves the analysis of the kinds of change to which our eyes are responsive. For this purpose it is best to speak of the light-color sensations, since the intensity of the light is itself a factor of the composite

result. For the purposes of color this change means that with added white light the color grows brighter, and with added black it grows darker. In addition for colors of the spectrum there is the gradual change as for example of a yellow that grows more towards the orange, or a yellow that becomes greenish. We must also think of the spectrum as converted into a circular ring, joining the violet and the red ends, the mixture of violet and red forming the purple. In addition there is a third type of change which may best be expressed by the term of *saturation*, which means that a red is as red as it can be, and that a departure from this means a lack of saturation. Combining these various changes it has been estimated that the eye can distinguish a large number, certainly two thousand or more, different color impressions, though naturally the differences would not receive ordinary names. In practical work in dye-houses, color scales are in use involving a very large number of distinctions. But this fact in turn means that colors when mixed fuse into a merged effect; nor is it the case that the resultant mixed impression can be obtained only by using one and the same set of components. The principle of color mixture that best illustrates the processes is that of rapid revolution; and the nature of the results will be gathered from the demonstrations. The principle of the after-image, or after-effect, thus involved is explained in the text.

2. Complementary Colors. The most striking fact in color-perception is that a pair of colors such as red and green, or blue and yellow, when combined, instead of giving an intermediate color, as for example red and yellow giving orange, or red and blue giving purple, will neutralize and give no distinctive color

at all, but a neutral gray. It is possible to find a complementary color for any color tone. This, however, is but one definition of complementary color. A second mode of reaching it is to subtract from the spectrum one color, and the mixture of the remainder forms the complementary. This likewise is shown in the demonstration. A third mode of reaching it is through fatigue. The eye when fatigued for red will see neutral light as green, and vice versa. In this connection may be mentioned also the fact of color contrast. This is of two orders: first, simple, or background contrast, which expresses the different appearance of a color according to the background against which it is seen; and second, the distinctive complementary contrast, which once more shows complementary color as a contrasting color with the major stimulation. This is in a sense subjective, and appears instantly without fatigue, as the various disks with a colored sector and a black-and-white ring show.

In this connection attention is called to the distinction between the positive after-image and the negative after-image. The positive after-image expresses the rather long period which an impression remains on the retina, and which makes possible its fusion with succeeding impressions. It is difficult to catch the positive after-image separately as such, but if one allows the eye to wander rapidly across a checkerboard, there appears for an instant an after-image of the board which is an exact reproduction of the board itself. If the checkerboard be looked at a little longer, then the negative after-image appears, lasts much longer, is partly a fatigue effect, and is distinguished by the fact that all the white squares appear in the after-image as black, and all the black

ones as white; while in the positive after-image the white squares appear as white and the black as black. The main effect of the positive after-image is in the fusion of successive impressions. It forms the principle of color-mixture, and it is the breaking up and avoidance of this fusion that is necessary to get the perception of movement through interrupted glimpses. The negative after-image of colors appears in their complementary colors. While the negative after-image need not be a fatigue phenomenon, the best illustration is the persistence as a deep purple ball of a view of the golden setting sun. It is clear that complementary color contrast shows the same kind of an effect, but without reaching the state of fatigue.

3. Color-blindness. Our knowledge of color-perception is markedly increased by its abnormal varieties. It is not wholly clear how the color-blind eye is defective; but the most marked type is that of a confusion of red and green with one another and with gray. Whether there are types within this group, of red-blindness and green-blindness, is again doubtful; but it is clear that the frequency of color-blindness shows the absence of one of the constituent factors of color-perception. Color-blindness should not be confused with weakness or subnormal capacity to make color distinctions. The latter is subject to education, and does not follow the characteristic confusions of the color-blind. The most common classification is that of regarding the normal eye as perceiving both black-and-white distinctions, red-and-green distinctions, and blue-and-yellow distinctions; next the ordinary form of color-blindness perceiving black-and-white distinctions and blue-and-yellow distinctions, but not the red-and-green; and third, the totally color-blind, who perceive black and white alone.

4. Color Theories. A theory of color must accordingly be able to state these facts in terms of the theory, and in a measure to account for them. The older theory bears the name of Young-Helmholtz. It assumed the existence of three elements, a red-perceiving cone, a violet-perceiving, and a green-perceiving. This was of course a pure hypothesis and increased observation shows less and less in its favor. The rival theory or theories all agree upon some form of simple process, one aspect of which gives rise to the red sensation and another to the green, and so on for blue and yellow, and again for black and white. The various objections and details of these theories are too complex to be included. In conclusion it should be noted that distinctions of luminosity are involved in the black-and-white distinction, but may be separately tested by the minimum changes of brightness which the eye can distinguish—that is, independently of combination with color. Visual acuity, or accuracy of form-perception for varying distances, which is the common test of vision, again has no constant relation to accuracy of color-perception.

Topic XXIII. **Perception of Movement.** A final distinction which the eye makes is that between objects in motion and objects at rest. This is an inference from changes of position. Motion may be distinguished as progressive, such as that of a point passing against a background, or the hand of a clock moving across the marks on the dial, and phase movement, which shows successive appearances, such as the rotation of a ball, or a man running, or a bird flying. Both may be combined, the distinction being that of a man simply marking time and keeping step, or of actually stepping and advancing. The principle is sim-

ple. It can be shown that the eyes do not see while they move, and that, accordingly, we get a series of glimpses. From the combination of successive glimpses of changes of position, we form the inference of movement. This is the principle of the kinetoscope, or motion picture, and is exactly analogous to that of the stereoscope in that the latter makes solidity out of its elements, and the former makes motion out of an interrupted view of a succession of successive glimpses. It is essential that the glimpses be very short, and again that the interrupted periods between the glimpses shall be relatively long, so that the after-image of the one glimpse may have disappeared before the next comes; otherwise there would be mere fusion on the principle of color-mixture. The kinetoscope as demonstrated shows how the appearance of movement may be accurately reproduced if these two conditions be obeyed. In stantaneous photography has furnished the means of very exact reproductions of phases of movement.

CHAPTER IV.

HEARING.

Topic XXIV. **Hearing and the Perception of Sound.** The approach to the problem of the perception of sound puts the question, "What are the kinds of information which we receive through the sense of hearing, and how do we obtain them?" Hearing offers a direct contrast to sight in that the part played by inference is small and the direct effect of the impression is large. This appears likewise in the fact that the pleasure-and-pain value of sounds is decided, and finds its analogy in color for vision. But music as an art depends much more upon mere sensory values than do the arts appealing to the eye.

Another general approach is by considering the physical cause of the sensation, the physiological process, and the psychological result. In the case of tone, the physical cause is well known, consisting merely in simple properties of air-vibrations; variations in force, in rapidity, and in their mode of combination. It is characteristic of the sense of hearing that the ear can perceive cumulative impressions. Sounds heap up, like the murmur of many voices in a crowded room; and we have developed the power of attention necessary to listen to selected portions of what reaches the ear.

The simplest enumeration of the qualities of sounds would first recognize the general distinction between tones and noises, which will be discussed later. Of

both it is true that they have (1) direction, referring to their location in space; (2) intensity, which is the common distinction of loudness, a distinction also used in connection with the location and with other tonal effects; (3) that most characteristic distinction of pitch, which refers to a tone as high or low, and which is as distinctive for hearing as color is for vision; (4) that complex characteristic called quality, which determines a large range of distinctions such as those between one human voice and another, between the same melody played on the piano or on the violin, and so on; to which may be added (5) duration, a very different type of quality and one which in a sense applies to all sensations, but has a peculiar part in the distinctions of tones. It refers to the longer or shorter period of time during which the stimulus acts.

Topic XXV. Structure and Function of the Ear. It is necessary to understand how the physical stimulus of the air-waves makes its way through the auditory apparatus, and eventually reaching the parts of the auditory nerve, sets up there that action of which the perception of tone is the psychological side. Referring for details to the text and demonstrations, it may be noted in summary that the human ear consists of three divisions: one the external ear, including that part which is on the outside of the head and is commonly called the ear, and the opening or auditory passage at the end of which lies diagonally an oval membrane, the tympanum or ear-drum. This is the division between the external and the middle ear. The middle ear, together with the internal ear, lies in a hollowed-out, box-like portion of the temporal bone. The middle ear is filled with air, and must be

filled with air to maintain the same pressure on the inside of the tympanum as exists in the outer air. This is done by means of the Eustachian tube, which goes from the back of the mouth to this space in the temporal bone. It is normally closed by a valve, but during the act of swallowing, as again for a longer period during yawning, the valve opens, permitting an interchange of air, and thus constantly restoring the air-pressure. Besides the air, the contents of the middle ear consists of a chain of three bones: the hammer, the lower tip of the handle of which is inserted in the center of the tympanum and the rounded head of which plays into a hollowed portion of the second bone, the anvil, which in turn has a long process reaching downward, and at the tip of this process there goes off at right angles the third bone, the stirrup. The bones take their names from the shape of familiar objects. They are delicately articulated, and act essentially as a whole. A vibration of the tympanum brings about a modified vibration of the plate of the stirrup, which is set substantially parallel to the tympanum. This plate of the stirrup rests against a membrane which is the separation between the middle and the internal ear. The internal ear consists of a membranous lining following the hollowed-out portions of the temporal bone, and is filled with a liquid both within the membrane and around it. The internal ear consists of the vestibule, or common meeting point of two structures located at this point. Of these two structures the one is the set of three semicircular canals. These have nothing to do with the hearing, but form the organ of equilibrium, and will be considered later. There remains the very minute snail-shell, or cochlea, which contains the two organs of

hearing, and also the very considerable auditory nerve, or to speak more accurately the eighth cranial nerve, the fibres of which are formed not alone by the nerve of hearing but also by the nerve fibres supplying the semicircular canals.

One may consider the cochlea as a tube which is first somewhat complexly subdivided, and then coiled two and a half times upon itself. A cross section of one of these coils would show an undivided lower portion and an upper portion in turn subdivided into two by an oblique membrane, thus dividing off a triangular space in which, naturally following the spiral of the entire structure, lie the organs of hearing. It is not possible to be perfectly sure what constitutes a unit of this organ of hearing, and it may be safer to regard it as made up of a pair of arches of Corti with its strand of fibres of the auditory nerve, and the fibre of the basilar membrane upon which it rests, together with a group of inner and outer hair-cells to either side of each arch. The careful protection of this organ of hearing indicates the delicacy of the minute impulses in the liquid which is the final form assumed by the vibrations of the air.

Topic XXVI. The Processes of Hearing. The distinctions made by the sense of hearing are in the form of the recognition of sounds. Such recognition proceeds in terms of distinctions which in turn must have a physical cause in the character of the outer vibrations, a physiological process in the way in which the hearing mechanism is acted upon, and a psychological result in the distinctive sensations felt. We proceed, as usual, from the last, and summarize the distinctions leading to the recognition of sounds as (1) those of direction, referring to the point in space from which

the sound proceeds; (2) those of intensity of loudness; (3) those of pitch, which is the specific characteristic of sounds; (4) those of quality; (5) those of duration.

The perception of direction is a very poor one in the human ear, and is one of the powers presumably lost through the loss of the power of moving the ear, which many of the lower animals retain. The shape of the human ear is also but slightly helpful, while the funnel-shaped ear of the horse or cat is evidently a better collector of sounds. The mobility of the ear in a horse, in each ear pointing separately and thus exploring and testing the direction of sound, accounts for the accuracy with which such an animal locates direction. The difficulty of locating a sound, such as that of a cricket in the room, and again the serious difficulty of vessels at sea in a fog in locating the approach and direction of movement of another vessel—all this shows the relatively poor development of the sense of direction in the human ear as compared with the animal proficiency. The main principle of direction is that of the difference in intensity in the two ears. Hence it is comparatively easy to locate sounds definitely on the right or on the left, while sounds in front or in back, and again below and above, are readily confused. Tests are difficult for the reason that sounds are modified by their echoes, and this often enables one to distinguish between noises near the floor or above one's head. That the outer ear still acts as a reflecting surface is shown by the unusual effect of one's voice as one speaks while holding the hands in front of and close to the ears.

The perception of loudness has as its physical cause the energy or height of the air-waves. It is relatively

simple to test the capacity to make distinctions of intensity, and we constantly use it in locating a sound as growing or decreasing in loudness. We also use it in regulating the loudness of the voice, and in recognizing distinctions of shading in a musical performance. One may test this sense by observing how slight a distance a watch may be removed or approached from a fixed point, and the direction of the change of position be recognized. Another simple test is to drop a small shot on a glass plate with the ear five or ten feet away, and to note from what distance the shot must be dropped to produce an observably louder sound. A telephone instrument may similarly be used to record the same distinction. This power should not be confused with the acuity of hearing, which would be measured by the smallest sound that one can just hear. Persons differ in this respect, and in old age a diminishing sensitiveness of hearing results in the loss of slighter sounds.

The remaining auditory perceptions assume such a large part in musical distinctions that they are best discussed under that head. It should, however, be observed that the training of the ear is primarily for the distinction and recognition of sounds, and that in principle there is no difference between such recognition or appreciation of sounds that are not specifically musical and of those that are. It is possible to show that the physical cause of a musical tone is the regularity or periodicity of the vibrations, while an irregular and non-periodic tone produces a noise. All noises contain a tone element, and almost all tones a noise element. The distinction appears in language, which also represents the type of sound distinctions. The vowels are tones, and the consonants noises. The

names of these, such as dentals, which are noises made by the teeth, and linguals, noises made by the tongue, and labials, which are noises made by the lips, indicate the character of the noise, which is then vocalized by combination with vowels. The accurate recognition of speech shows the tremendous power of the ear in recognizing slight differences of sound and of associating meaning with these sounds.

Topic XXVII. **Musical Perception.** The perception of pitch refers to the distinction recognized as that of high and low tones. All tones and noises have a pitch more or less constant or variable, and the distinction between a man's voice and a woman's voice, between one voice and another, between types of noises, all involve distinctions of pitch. It is, however, easier to study them at their simplest. Such simple tones as made by tuning-forks or whistles or reeds bring out the special distinction of pitch. The keyboard of a piano again represents pitch distinctions, arranged, however, in a musical scale. The physical cause of pitch is the frequency or length of the waves. High tones represent very rapid air-vibrations, and low tones slower vibrations, and thus longer ones. The limits of pitch in a sense are similar to the limits of color for the eye, and are readily determined. It may be shown that air-vibrations can be seen when vibrating from five to fifteen vibrations per second, but do not form a recognizable tone until about from twenty-four to twenty-eight per second. These low, dull, vibrating tones are used only in connection with higher tones. The upper limit of hearing is tested by some form of whistle, which gives rise to a very slight, piercing, shrill sound. The upper limits vary, but a general average of from twenty to

thirty thousand vibrations or more is the result of the test. However, musical tones above four or six thousand vibrations are sparingly used.

The power to make small and definite pitch-distinctions probably varies more than any other sense capacity. While this should not be confused with musical perception, it is the basis of it. A test of the power of pitch-distinction, and also of the position of tones in the scale, is readily made by some tone-testing apparatus, or again by a series of tuning forks, each one differing by a few vibrations from the next. The most favorable interval for such tests are vibrations of from three hundred to six hundred per second, and within this limit a sensitive ear can perceive as higher or lower two tones varying by a vibration or two. The difference of such tones is often heard when it is impossible to say confidently which is higher and which lower. Ears less acute in this respect would vary almost indefinitely, so that to some ears even differences of fifteen or twenty vibrations per second are not very distinct and recognizable. When we leave the simple tests of the range of pitch and of pitch-distinction, we enter the special kinds of distinction upon which music depends. Before taking up this point it should be noted that another general quality of tones is their very brief after-effect, thus contrasting with the long after-effect of colors. Colors fuse readily if impressions are exposed eight or more per second. Tones remain distinct even though they follow one another at the rate of several hundred per second. All this is provided for by the mechanism of the ear. The principle of the physiological process for pitch-perception is one of selection; and we may think of the spiral series of end-organs as acting

selectively by the principle of sympathetic vibration; so that a tone of one pitch will set going only a definite unit or units of the hearing apparatus. On this assumption it is easy to construct the type of physiological processes correlated with pitch-distinction.

Topic XXVIII. Special Aspects of Musical Perception. The central distinction is that concerning pitch; but the power of pitch-distinction is essentially altered by the peculiar type of recognition of pitch-relations for which the term "sense of interval" may be adopted. The fact thus expressed is a peculiar, indeed a unique one in the field of sensation, for it expresses a sensitiveness to relations independently of absolute pitch. It must not be supposed that the fundamental elements of musical perception are possessed only by the few, or the musical in the technical sense. Everyone who recognizes a familiar simple tune whether played on one instrument or another, whether played on the upper octaves of the piano or on the lower, shows the essential recognition of the sense of interval; for the recognition that the succession of tones is the same expresses the essential fact. Viewing this fact more closely, it appears at once that the recognition of succession in terms of interval, which is called melody, does not apply equally to any and all intervals. It appears specifically that the human ear is sensitive to the recognition of certain intervals. It is the accounting for this fact that constitutes the successful analysis of tones.

The first stage in this analysis is the demonstration that the differences that we call quality, and which appear in tones of the same pitch but produced by different musical instruments, are all due to complication of the fundamental, which gives the domi-

nant tone, with the presence of overtones. Simply stated, all tones are complex, and the physical cause of this complexity is again a physical tendency for a string, a semi-enclosed body of air, or other musical instrument to break up into parts, and to have these parts vibrate along with the vibration of the string, etc., as a whole. The quality, the richness, the total effect of a tone is thus due to the kind and strength and distribution of overtones which accompany the fundamental. Nor must it be supposed that this type of distinction applies to music alone. It is just as true of noises and of speech; for speech is the result of using the vocal cords as an instrument, which is further reenforced and directed by the organs concerned in speech. Viewed as a single instrument, the voice can give rise to tones of its own pitch; and such distinctions as the vowels o, a, the German ü, and so on, must be due to difference of quality, the quality resulting from the different positions of the cavity of the mouth, which by reenforcing different types and ranges of overtones produces the resulting sound. This is not a matter of speculation, for it has been demonstrated that a series of tuning forks of varied pitches, when sounded together, actually reproduce the tones o, a, and so forth.

Returning to the sense of interval, we reach the essential distinction between the musical and the non-musical ear. The musical ear recognizes the *correctness* of intervals, and, as indicated, of *particular* intervals. The two most common intervals are the octave and the fifth. The octave is represented by the relation of one to two, and the fifth by the relation of two to three. The other intervals composing the musical scale also represent, for the most part,

simple numerical relations. The conditions leading to the adoption of the musical scale are too complicated to be here considered, but the vibration-rates for the middle octave are given below:

c'	d'	e'	f'	g'	a'	b'	c''
256	288	320	341.3	382	426.6	480	512

The relation of c' to c'' is that of one to two, and forms an "octave"; the relation of c' to g' (2 to 3) is the "fifth"; the interval c' to f' (3 to 4) forms a "fourth"; c' to e' (4 to 5) forms a "major third"; c' to a' (3 to 5) is a "major sixth." Omitting details, it may be said that these, together with one or two other intervals, constitute the most pleasing and the most commonly used intervals in simple melody, while other intervals are used with less consonant effect.

In view of all these considerations, the striking fact remains that we are more sensitive to interval than to pitch, more sensitive to relations of tone that are slightly out of tune because the interval is flat or sharp than to any absolute pitch distinction. The explanation for the existence of this sense goes back to the unconscious education which the ear is constantly receiving in the relations of fundamentals to overtones in any complex tone; for these are the same relations that are repeated in the interval. The further complication of music is the obvious and essential one of the existence of harmony, namely that we hear the resultant effect of many tones combined. If there were only melody and no harmony, we should be reduced to tunes that could be played with one finger on the piano. It is obvious that the existence of harmony enormously increases the range and

nature of musical effect; but still more, harmony gives the ear a correctness of appreciation of interval which supplements and perfects that supplied by melody. Thus a piano-tuner adjusts a given key not merely by testing whether in connection with a lower and a higher tone it forms a proper scale, that is, a proper interval or succession; but he tests it still more by placing the given tone in a group of three or more, that is, a chord, observing whether the sound of the combined chord is correct.

In conclusion let it be noted that musical perception supplies the simplest conditions for the analysis of tones, and further shows how the distinctions which the ear recognizes are appreciated. It must be ever borne in mind that these principles are equally applicable to the distinctions of speech and to those of noises, but that here they are complicated by all manner of recognitions which cannot be expressed in terms of pure pitch or quality. Consideration should also be had of the factor of duration. This expresses not merely the fact that the ear is sensitive to time distinctions, but that these time-relations enter into and combine with other factors of musical effect. As a pure time-distinction one may refer to the telegraphic language, which is a code combining long and short clicks into arrangements of letters. So also in music, time is expressed by whole-tones and half-tones and quarter-tones, and so on, and the duration during which a tone is sustained contributes much to its effect. But in addition there is the time-relation of the tone itself. Thus when we distinguish between a violin and a piano tone, it is true that the main distinction is one of quality, which means that the piano brings out certain overtones in a different intensity

and distribution than does the violin. It means, however, equally that the mode of swelling, of increasing of the piano tone and the rapidity with which it reaches its highest effect, and then in turn with which it dies out, give it an entirely different time-effect from the long-drawn-out bowing of a violin tone. Thus duration, along with intensity, pitch, quality, and the developments of pitch and quality into the sense of interval, and the resultant appreciation of melody and harmony, give the range of musical perception.

CHAPTER V.

SMELL AND TASTE.

Topic XXIX. **The Sensations of Smell and Taste.**

This group of sensations is important as illustrating the range of application of what are commonly known as the lower senses. This term refers primarily to the fact that these senses are closely attached to use or service in terms of protection, and have slight intellectual development. Of the two, smell is the more extensive sense; and in terms of evolution sight and smell occupy a peculiar position, which is due to their leadership as distance senses. It is clearly of importance to an animal to become aware of objects of danger or of interest at long range, and there is some reason for dividing organisms into those that appreciate long range situations by smell and those who appreciate them by sight. The birds illustrate the latter, having long-range vision and a poor sense of smell. This is proved by Darwin's experiment of distributing paper bags containing meat along the sea-beach and noting that the condors swerving about would fly near to, but not examine the paper bags, indicating that they could not smell the contents; but that when one bird had accidentally broken through the bag and the meat was exposed, they instantly pounced upon all of them and quickly devoured the meat. Similarly, birds of prey discover the presence of carrion at long range, and show their superiority of vision, which we have

recognized in the phrase "the eye of the eagle." Such animals as the dog show a corresponding superiority of the sense of smell and a lesser development of vision. In the human brain the shrunken appearance of the olfactory lobes is very striking, indicating that in man this sense is degenerate.

The sense of smell protects the respiratory passage, so that only wholesome air may be breathed, and the alimentary canal, so that only wholesome food may be swallowed. The lower passage of the nose is the respiratory passage, and the upper chamber, in which the end-organs of smell are situated, is only distinctly stimulated when we deliberately sniff the air to perceive odor. Both the anatomy and the physiology contribute little to our knowledge; and it is equally true that the physical cause of distinctive odors is not definitely assigned. Odors are accordingly classified empirically, using for the most part the names of flowers and fruits and essences prepared by nature or by manufacture. Thus we speak of a violet-like odor, or a peach-like odor, or the odor of tar or wax, and so forth. The general reaction to odors is one in terms of their pleasant or unpleasant character, and in a moderate way an esthetics of odor is used.

The sense of taste is much more limited, and refers in the main to the simple distinction of sweet, sour, bitter, and salt. Here again there is distinct use for protection of the alimentary canal. We need salt, and thus have a taste for it. Similarly we need sweets, though here the sense of luxury makes possible an esthetic development of satisfaction. The combined use of taste and smell in the recognitions of eating forms an excellent example of a psychological complex, that is, of a single recognition due to composite

factors. Thus if, with the eyes closed, a morsel be placed into the mouth, it might at once be recognized as a bit of raspberry jelly. Such recognition is, as all recognition, in terms of quality; and we may enumerate the qualities as the smoothness, the softness, the sweetness, the acidity, the peculiar flavor, and equally the temperature. Together these qualities constitute the basis of recognition. Some of them are tactile, like the smoothness, or motor, like the softness; the acid and sweet are taste stimulation; and the flavor belongs to smell.

It can readily be shown that the larger part of food recognition is due to odor or flavor. When affected with a cold, we taste food but little; but the sense of taste itself is not affected, only that of smell. So persons who have no sense of smell distinguish salt, sweet, bitter, as well as others, but they do not distinguish the flavor on which the recognition of food depends, and experiment confirms this conclusion. It can be shown that with the nostrils held we should fail to recognize such distinctions as veal and chicken, or again, scraped apple or scraped potato, or again tea and coffee, or in brief all flavors which are used in cooking. These are appeals to the nose, though the attention is so much more concentrated upon the mouth that we wrongly refer the source of sensation to taste.

While thus these senses minister to protection and useful recognition, they have a limited intellectual development. It is clear that the dog in distinguishing the footsteps of his master from hundreds of others makes an intellectual distinction. It is a distinction quite parallel, though not as explicit and conscious as that which a druggist might make in

recognizing the contents of bottles from their odors. We moderately use this sense of distinction for smell and also for taste, but we are mostly sensitive to the pleasant and unpleasant side thereof. But in chemistry, as well as in food preparation, delicate perceptions of flavor and taste enter and form the basis of distinctions. Such a professional use of this sense as that of tea-tasting, in which the values of teas are assorted by the verdicts of the professional on the basis of flavor and taste, indicates the possibility of intellectual use of such senses. It may be added that tests of power to distinguish slight differences in odor or in taste, and again of the power to detect the presence of small amounts of familiar stimuli, yield results which show a great variety according to the particular objects used. In some respects the sense of smell is very delicate, the nose recognizing the presence of so minute a fraction of a grain of musk that it even defies chemical analysis. On the other hand, for other types of substances the recognitions are vaguer and the power of distinction is less marked. It may further be noted that both taste and smell are subject to contrast and to fatigue, so that we get used to odors and also tire of them, and that overstimulation readily enters.

CHAPTER VI.

TOUCH AND MOVEMENT.

Topic XXX. The Tactile Sensations in General.

The word *touch* is popularly used to cover a variety of sensations obtained through the skin. It is easy to recognize that many different types of sensation are here present. Temperature is most readily distinguished from the rest. The active use of the skin in *feeling* as against *touching* indicates the composite play of movement in connection with touch. We know that there are only two types of sensations, those resulting from the stimulation of a special sensory surface and those accompanying the contraction of muscles. The latter are called kinesthetic, and they are of special relation to touch not only because of the constant use of motion with touch, but because of the extensive nature of the tactile surfaces and the large variety of muscle-sensations that merge with tactile ones.

Classification of touch qualities is not easy, and the best is open to considerations of convenience. We may distinguish first the bare sense of *contact*, which gives at the least the sense of awareness of a touch feeling, like that of a fly alighting upon the skin or of brushing against a spider web. The skin is at many points aided by sensitive hairs which give increased sensitiveness to such bare information of contact. The thinness of the skin, as over joints, also illustrates a delicate variety of this simplest type of tactile sensitiveness.

The sense of *locality* represents the fact that the position of a touch upon the skin is localized approximately or accurately. This is a factor of the distribution of the nerves of touch. There is no danger of confusing a touch on the foot or on the shoulder-blade with one on the hand. Similarly, a touch on the hand is readily distinguished from one on the elbow or upper arm, and again on the right hand from one on the left hand. Bringing these distinctions to their limit, different points on the finger-tip would in turn give a difference in feeling; but eventually this vanishes. The standard test to show this fact and as well to illustrate the distinction of such sensibility is the "compass-point" test. This shows that the minimum separation of two points necessary to have the points felt as two varies decidedly on different parts of the skin area. The distance is about three or four millimeters for the palm of the hand, nine or ten millimeters for the back, and one and one-half or two millimeters for the tip of the forefinger, while very coarse areas, as between the shoulder-blades on the back, may require a separation of the points to twenty or twenty-five millimeters—substantially an inch. The natural way to account for this difference of sensibility is by supposing that in the coarsely perceiving areas relatively few fibres supply relatively large surfaces, while on the finger-tips a large number of nerve-fibres supply a very small area of skin. This distribution would then account for the ability to localize better on the finger-tip than on the palm of the hand, and it would give a more distinctive quality to the more finely perceiving areas.

From this same condition arises the most characteristic form of tactile distinction, that relating to the

space qualities, which may be enumerated as *form*, together with *size*, which in turn includes *length* as well as *area*. The principle is best illustrated in the perception of form, and of this the simplest type would be the distinction between a square hollow tube and a round hollow tube of the same size. The tests at once show that whether or not the distinction is felt depends upon the size of the tube. Quite large tubes, half an inch or more in diameter, will not be distinguished as to form on the back of the hand or even on the palm of the hand, but tubes of half the size will be accurately distinguished on the finger-tips. There is a yet finer tactile organ, namely, the tip of the tongue; and here a pair of needles but a quarter of a millimeter apart may still be distinguished as two. The tongue can also distinguish minute differences of form, such as that of a needle with a round eye or a needle with an elongated eye, which give no impression when pressed on the finger-tip. It is this type of distinction that the blind practice in reading raised letters, and it is easy to show how difficult such distinctions are, even in very large letters. It must be added that the actual way in which the perception of form by touch best proceeds is through *feeling*. The finger rapidly moves over the surface and thus decidedly increases the clearness of the form distinction.

As each sense has its specific quality, so that of touch gives rise to texture, and the simplest example of this is the distinction between rough and smooth. Regular surfaces may be arranged by weaves in strands of different thicknesses; and thus the sense of roughness and smoothness may be accurately tested. Here again the active sense of feeling makes distinc-

tions more readily than the mere sense of contact. This touch quality is not limited to roughness and smoothness, but extends to allied distinctions, as the feel of the pile of velvet, the different types of composite qualities as wetness, stickiness, oiliness, grittiness, and so on.

The sense of *pressure* upon the skin represents a different phase of contact, and one which in the passive form is not of large practical use. It may, however, be tested by the power to distinguish between differences of pressure or of weight resting upon the finger. Such a sense is relatively coarse, distinctions on the palm of the hand being about $\frac{1}{5}$ or $\frac{1}{7}$; which means that the weight must be increased by this amount before it is clearly perceived as heavier. When, however, the active sense of pressure is used, as in lifting weights, distinctions as small as $\frac{1}{15}$ can under favorable circumstances be made; that is, a "short" pound of fifteen ounces could be detected by lifting as lighter than a true pound of sixteen ounces.

Topic XXXI. The Sense of Temperature. Quite distinct from this group of sensations resident in the skin is the sense of *temperature*, it being very obvious that a feeling of warmth or of cold is of a wholly different nature than that of weight or of form or of texture. It is also true that in terms of origin and of function temperature has a very different status. It is now known that there are special temperature organs, and further that the particular points of the skin at which the sense of heat as best felt are different from those at which the sense of cold best appears. It may then be assumed that there are special nerves to convey impressions of heat, and probably special nerves to convey sensations of cold as distinct from

heat. Temperature has a special body-regulating value, owing to the fact that we are warm-blooded animals and that the maintenance of a constant temperature is essential to health and vitality. As a consequence, marked deviations of temperature affect the physiological mechanism, and all functions suffer in intense cold or again in intense heat. But apart from this general regulation, there is the fact that what we feel as cold is the loss of heat from the body, and what we feel as warmth is the adding to the heat of the body. It thus results that the temperature-sense, if compared with the thermometer, is constantly misinforming us. Thus a surface of flannel and a surface of iron exposed in the same room are really of like temperature; but the iron feels cold because it takes heat away from the body, and the flannel feels warm because it reflects heat back to the body. So similarly the sense of temperature is subject to contrast; and if the one hand be placed in cold water and the other in hot, and then both simultaneously plunged into lukewarm water, the hand that has been in the cold water will feel the lukewarm water as hot, and the other will feel it as cold. These contradictory sensations will gradually disappear as the new adjustment takes place. Similarly in coming from outdoors the room may seem warm, and in leaving a warm room for the cold outdoors the most marked sensation appears by contrast. Owing to this mode of reaction of the temperature sense, one must determine its power of making distinctions with reference to definite temperatures; and it may be said that for moderate temperatures of from 80 to 100 degrees Fahrenheit distinctions of one or two degrees, or even less, can be made by the finger under favorable conditions. One

may also learn to associate definite feelings with absolute temperature, thus gauging the reading of the thermometer by the feel of the air or water.

Topic XXXII. **Kinesthetic Senses.** The sensations accompanying movement may be considered with reference to their *extent* and with reference to their *intensity*. In all movement we accomplish work, and work is measured in foot-pounds, the foot representing the extension and the pound the intensity. Considering the latter element first, we know that in lifting a weight there is a double process, that of the feeling accompanying the outgoing effort, and secondly that of the feeling of the return sensation. It is the adjustment of the one of these to the other that makes it possible to exercise energy in accordance with intention. Thus the experience of raising a pitcher of water and finding it flying up in the hand shows that the very act of lifting the pitcher involves an anticipation of the presumable weight of it by means of the presumable effort necessary to lift it, while the return sensation in this case reports that the pitcher (empty when it was supposed to be full) is unexpectedly light. The effort being released, it expends itself in raising the pitcher up in the air. This double process of the outgoing effort and the return report is also the basis of skill, whether exercised by the sense of touch or by touch and sight. The special mechanism of this regulation will be considered later. At present it is sufficient to recognize the nature of the kinesthetic sensation and its connection with the sense of touch. Thus *active* touch represents more particularly the resulting increase of feeling from moving the hand about, at the same time focusing the attention upon the tactile sensation, while the

kinesthetic sense implies the use of muscular contraction with the attention directed either to the degree or the extent and distribution of the contraction. It is clear that active touch not only gives a better sense of weight by lifting, but it gives a better sense of form, and again of length or of area, by the complicated process of feeling. In lifting weights there is the feeling of pressure of the weight against the skin, but this is less accurate than the sense of effort due to muscular contraction.

Attention should be directed to the *joint* sense, the best example of which is its use in feeling the thickness of a board or a book or a sheet of paper or a cloth between the thumb and forefinger. This is again kinesthetic in type, and represents a remarkably accurate distinction. It will be simply tested by placing between the thumb and forefinger a random number of pages in a book, and trying to select with the other hand an equal number. Differences of two or three pages in a hundred are readily told; and experts can judge the weight of paper or the thickness of cloth quite accurately by this means.

Topic XXXIII. Sensation in the Guidance of Movement. There remain to be considered various types of sensation which are specifically developed with reference to the guidance of movement, including the locomotion of the body as a whole from place to place, as well as the specific movements by which the mind expresses itself in conduct. These are by no means of like type, but have in common the illustration of the sensory guidance of movement.

The Sense of Equilibrium. The first type relates to the specific sensations by means of which the equilibrium of the body is maintained in movement,

and also the sense of direction is guided. In considering the ear, we found a set of organs, the semi-circular canals, which have nothing to do with hearing, but which have been shown to be the special organs of this sense of equilibrium. The normal function of these organs is to indicate the slightest departure from the normal vertical position, and thus to stimulate the righting or correcting movements necessary to restore equilibrium. The three canals at once suggest the action of spirit-levels, and are doubtless related to the three dimensions of space. Two of the canals are vertical, the one running fore and aft, and the other from side to side; while the third canal lies below them in a horizontal position. It is this horizontal canal that seems especially sensitive to disturbance, being aroused by turning rapidly on one's heel, thus inducing the familiar sense of dizziness. The mechanism of this action is the pressure of the liquid within the canals against the nerve-endings in the swollen ends of the canals. Similarly sensations of disturbance in the vertical fore-and-aft canal would be induced by swinging, while the irregular movements of a tossing ship would seriously affect all the canals. While the action of the canals is best observed in their disturbance in the sense of dizziness, it is obvious that their normal function is through such disturbance to induce the slight compensating movements necessary to the restoration of equilibrium. The susceptibility to dizziness, and to dizziness in the various planes, varies in individuals. Its most familiar symptom is a lack of coordination between the specific sensations of the canals and vision. Thus after spinning on one's heel the walls of the room seem to go around, which is of course an illusion in-

duced by this conflict between the "semicircular" sensation and the attempt of the eyes to catch up to them. It is interesting that the necessity of such a guiding sense was hardly suspected until in recent times, while the demonstrations of the semicircular canals as the organs of the sense of equilibrium is relatively recent.

Another example of sensations guiding the sense of movement is that referring to *passive locomotion*, of which in recent times we have large experience. It has been shown that we have no true sense of movement, but infer it only from irregular jars and jolts, or from the pressure of the wind against the face, or again from the passing of objects along the road, and finally from some slight disturbance in the semicircular sensations. This is another example of a *complex* dependent largely upon inference. One illustration of it is familiar. When sitting in a railway car in the depot and the train adjoining moves out, there is a strong feeling that one is moving backwards. This is illusory, and is the inference of backward movement from the forward movement of the next train,—just as in traveling we pass fences, trees, houses, etc., and *their moving backward* becomes an index of *our moving forward*. The very fact that we can thus induce a feeling of movement from a sensation shows how largely inferential it is. The sense of movement is decidedly increased in riding in an open trolley by the pressure of air against the exposed parts of the body, and again by all the irregularities of jolt and jar. Moving in an elevator gives a new direction of up-and-down sensation, and in the moment of starting and stopping, there is a decided and often unpleasant feeling, which is of "semicircular"

origin. In this direction, too, illusions of motion may be produced.

The Sensory Guidance of Manual Skill. A very special relation obtains between the eye and the hand, and illustrates the complex guidance contributing to manual skill. The hand carries out its movements under the direction of the eye, but also under the guidance of kinesthetic sensations. As a consequence, the kinesthetic sensation alone will suffice, though with diminished accuracy. Thus in learning to write with my eyes open, I have incidentally learned to write with my eyes closed. The kinesthetic sensations are adequate to induce the proper forms of the letters. Similarly in learning to use the typewriter one depends largely upon vision, though the touch system throws a fairly independent guidance upon kinesthetic sensation; and naturally the blind use the typewriter freely on the basis of kinesthetic sensations alone.

The principle is even better illustrated in the relation between speech and hearing. The child learns to speak by the double regulation of feeling the proper positions of its own vocal mechanism and of correcting the spoken sounds by the criterion of the ear. Thus while learning to speak by ear through hearing the sounds of his own voice, the child incidentally, but quite inevitably, learns to speak without hearing, and through the kinesthetic sensations of the vocal cords alone. Accordingly, if in youth or adult life one becomes deaf, one does not lose the power of speech, the kinesthetic guidance remaining adequate. Even more than this is shown by the natural relation that connects deafness with muteness. There is no physiological, but only psychological reason why the child

born deaf should become a mute. It lacks the incentive to speak supplied by hearing its own voice. In recent years, deaf children are taught to speak, though naturally not as accurately as hearing children, by the guidance of the kinesthetic sensations alone. They are encouraged to make sounds and to note the position of lips and throat of the speaking teacher. The utterances are corrected again and again, until they acquire the entire speaking process by kinesthetic guidance.

Topic XXXIV. **The Space and Time Relations of Sensations.** All senses have the quality of duration, but our knowledge of the sense of time is not gained equally from all of the senses. The *auditory sense of time* is best developed. The ticking of a clock, as well as the rhythmical movements, suggests how this form of guidance is largely thrown upon the ear. In rhythmical movement, as in dancing, and in keeping step, the music gives the time guidance; such rhythm of expression requires the auditory accompaniment for accuracy as well as for pleasure. The motor tendency is shown in the impulse to beat time to marches or similar melodies. It is also true that the ear will more accurately judge slight differences in interval, and gauge intervals of time accurately, of which again the telegraphic language is an admirable example. Time-relations for vision are of a totally different order, and fusion introduces complications.

In a very similar sense the eye is the great *space-sense*, and judgment of positions in space are largely visual. It is true that the ear has a spacial reference in the location of sounds and in the estimate of their distance, but it does not grasp space-relations directly as does the eye. This contrast further shows the ear

to be the great successive sense, giving relations of *succession*, as melody, or again in speech and in the development of the drama, while the eye gives the sense of *simultaneity*, of contrast in composition, permitting of a large field and quick change of attention. The ear attends to but a single impression, but receives many impressions in rapid succession. The eye is confused by too rapid succession of impressions, and perceives motion only, as we have seen, by inferences from successive changes of position.

Of the remaining senses, touch and the kinesthetic sense contribute considerably to the perception of space; and the essential space-concepts may be obtained, as in the case of the blind, from these alone. Thus there have been blind mathematicians, and even blind sculptors. The remaining senses hardly enter, except to the slight extent to which successive effects, notably those of contrast, affect taste and smell sensations.

CHAPTER VII.

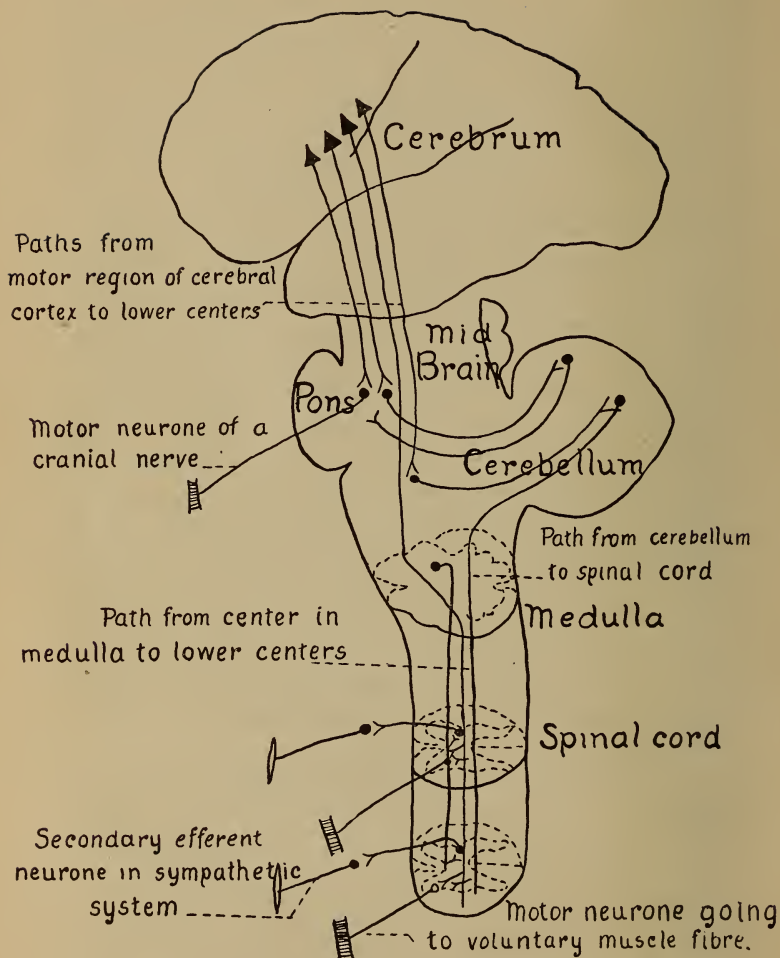
THE NERVOUS SYSTEM.

Topic XXXV. **The Nervous System. General Structure.** The nervous system may be thought of as composed of units of structure, which in turn are combined into systems serving different types and varieties of functions. The gross dissection of the nervous system reveals in certain sections masses of fibres, and in other sections groups of cells or cell-bodies of various forms. These in turn are massed and grouped in complicated relations. To bring some order and system into their description, a general topography of relation of parts is necessary, and as well a microscopic study of the structural units of which these masses are composed. The models will serve best for the first problem, and diagrams prepared on the basis of microscopic sections will illustrate the second.

The "central" nervous system refers to the contents of the brain and spinal column, while the "peripheral" nervous system refers to the whole set of connections from sense-organs inward to the central nervous system, and to the connections outward from the central nervous system to the muscles and glands of the body. The word nerve, or nerve-trunk, as used with reference to the optic nerve as a sensory nerve, or again to any of the motor nerves serving such muscles as the biceps or triceps muscle, refers to the connection of nerve-fibres on their way from sense-organ to center, or from center to muscle. There are

thus two ways of describing the make-up of the nervous system; and each is convenient. No confusion will result from combining both methods. The first would then describe the peripheral nervous system as made up of nerves, in turn sensory or motor, and the sense-nerve-endings, like the rods and cones in the eye or the special end-organs of taste or smell, together with the nerve-endings imbedded in the muscle fibres, through which the impulses to contract reach the muscles. Within the central nervous system one would speak of nerve-fibres or connections and of nerve-cells. Thus the outer layer, or cortex, of the brain, represents a great mass of these nerve cells, while the great tracts of fibres from brain to spinal cord and running down the spinal cord would be spoken of as fibres. In reality, however, each unit of the nervous system is a cell or cell-body with a double set of projections. Such a unit is called a neurone. This method of describing the nervous system is unquestionably the more accurate, and should remain in the background when we use the convenience of the other form of description. The nervous system thus described becomes a complicated chain, a cluster of neurones which serve a unified function.

Topic XXXVI. The Parts of the Central Nervous System. It is convenient to divide the central nervous system into first, the spinal cord; second, the enlarged end of the spinal cord, called the medulla; third, the brain-stem, which is the further continuation of the mass of organs built up into the medulla as a sort of stem for the great overhanging masses, of which the two great parts are the cerebral hemispheres, or big brain, and the cerebellum, or little brain. A further convenient term is that of the basal ganglia as refer-



Motor Tracts.

ring more particularly to the mass or collection of nerve cells grouped about the head of the brain-stem.

The spinal cord is to be conceived both as a conductor of impressions, which is represented by the fibre-columns or tracts—and in this sense it is a means of communication between the higher portions of the nervous system in the brain and the set of muscles and sense-organs of the parts of the body below the head,—and also as a center for reception and expression of function. In a general way it is the cell-bodies or the gray matter that represents the function of the spinal cord as a center of impressions, and the white matter of the fibre-columns that represent its function as a conductor of impressions. As a center of impressions the spinal cord must be thought of as a series of centers, and naturally changes its function at different levels. At the lower levels the nerves leaving the spinal cord are going to the muscles innervating the legs; and similarly incoming nerve fibres at this level are bringing in the tactile feelings from the lower part of the body. In the middle areas the spinal cord is a center functions for the chest; and at the upper level, between the shoulder blades, the great nerves go off to innervate the muscles of the arm and hand; and equally at this level are received incoming sensory nerves carrying in the impressions from the skin of hand and arm. While it is true that the functions served by the spinal cord as a center are typically “lower” functions, of the type to be called reflex, it must be remembered that this is but true in general, and that functions of the same order also are served by parts of the central nervous system within the brain. This is partly the mere matter of position, since clearly the sense-organs of the head would have

their lower-type centers within the brain and not at the lower level of the cord. Viewed anatomically, the appearance of a cross-section of the spinal cord shows in its imbedded central part, shaped like the letter H or the wings of a butterfly, the collections of gray matter; and surrounding this the several fibre systems which represent the basis of the spinal cord as a conductor of impressions. The minute anatomy of the cord may be gathered from the models and charts shown.

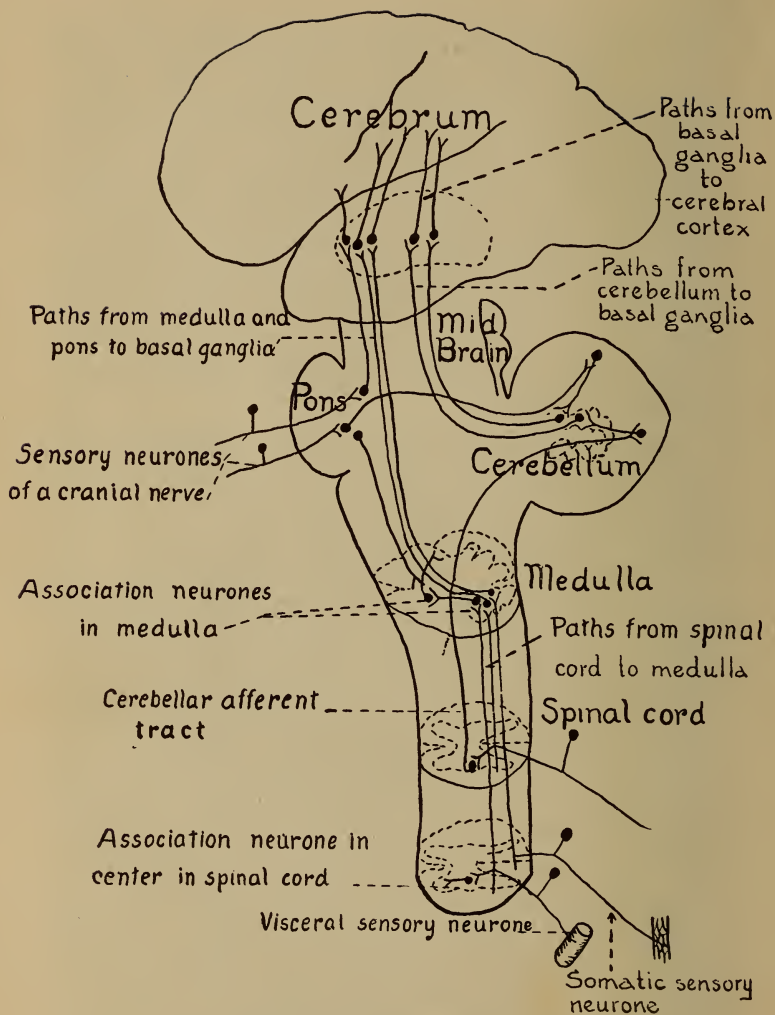
Attention is directed to the manner of function at each level of the spinal cord where sensory nerve-fibres enter and the motor nerve-fibres issue. It will be seen that along with each such part there is a swelling or ganglion, into which the entering nerve-fibres go, and from which they are redistributed to the spinal cord, which they enter on the posterior side. The motor nerves issue from the anterior side, pass by this ganglion, and go out to the muscles.

Viewing these provisions from the neurone point of view, we consider a motor cell as situated in the anterior horn of the gray matter of the spinal column. This is a complex, many-branched cell, with a prominent nucleus, and from it there goes out one main projection, which eventually ends in the muscle, more or less distant from the cord. A type of such a unit is shown in the diagram (Plate IV). Similarly, referring to the diagram labelled "Path of Conduction in the Spinal Cord," it will be easy to trace the first, or sensory neurone, which begins in the bit of the skin in which its terminal organs are imbedded, passes inward as a single nerve-fibre to the spinal ganglion, which it enters and from which it emerges ready to travel upward in the spinal cord in that portion de-

voted to sensory functions. Here in turn it ends in a many-branched ending near to the beginning of the next neurone, the cell-body of which, again many-branched, intertwines with, without actually touching, the final endings of the first neurone. This in turn goes upward to the higher connection. All sensory neurones in this diagram are indicated by upward-pointing arrows. Similarly parts of the motor neurones are indicated by downward-pointing arrows, the connection showing how they issue at different levels. There are also shown the type of cross-connection by which a sensory neurone reaches the opposite side of the spinal column.

Referring to the text, as well as to the plates, for detailed descriptions of the other portions of the nervous system, we shall at once proceed to a description of the structure of the brain.

Topic XXXVII. The Structure of the Brain. The brain may be considered as composed of the cortex, or outer layer, usually about three-eighths of an inch thick, markedly convoluted, and the projecting connections from it and into it from lower nerves. Here it may be noted that the contrary arrangement obtains from that in the spinal cord, where the fibres are on the outside, while in the brain proper they are imbedded within the gray mass. It is this inversion that contributes much to the complication of following the paths or tracts. Further, the brain consists of the two hemispheres with a deep cleft or fissure dividing them. These two hemispheres are joined by a great mass of transverse fibres which form the corpus callosum, or hard body, shaped somewhat like a sickle, which serves to make the two hemispheres function as one. A large part of the interconnecting fibres belongs



Sensory Tracts.

to the systems connecting coordinate portions of one hemisphere with those of the other. Next there is imbedded towards the center of the combined brain mass a set of further collections of gray matter set about the head of the brain-stem which collectively we may call the basal ganglia. These represent intermediary stations for the reception of lower chains of neurones and the beginnings of upper chains of neurones. Since the fibre systems must in turn pierce these, and in part go around them, the anatomy becomes very complex. Finally, there emerges through this mass the great stalk or main body of the stem, which contains the paths of conduction from and to the spinal cord and brain. Still another portion of the conducting fibres are those joining the hemispheres with the cerebellum. The cerebellum is composed of a central lobe and two lateral lobes, and these in turn are connected by a massive strand of fibres running around the central brain-stem and called the pons, or bridge.

The special function of the cortex requires some further description of its divisions. These may be readily understood by observing that each hemisphere is divided into four lobes, the frontal lobe, the temporal lobe, the occipital lobe and the parietal lobe. The divisions between these areas may in turn be understood by observing, first, that the chief fold or great fissure of the brain is one that runs diagonally from the junction of the frontal and temporal lobes, observing next and obliquely to this the great central fissure, called the fissure of Rolando. In the diagram labelled "Sensory Tracts," as also in the one labelled "Motor Tracts," the brain is shown in outline with these two fissures alone. The frontal lobe is roughly

speaking the part of the brain forward of this great central fissure. The parietal lobe is that part of the same back of this and as far back as the occipital lobe, which is indicated by the projection of the great crease or fissure of Sylvius. The temporal lobe is that part below the fissure of Sylvius, and the occipital lobe the rear portion overhanging the cerebellum. It should further be noted that while these areas refer mainly to the side or lateral view of the brain, parts of the cortex appear also on the median and under, or basal view. While these divisions of the brain and nervous system are adequate for an understanding of the function, it is desirable to study the many minute divisions indicated in the text and by the models and diagrams.

As to the minute structure of the cortex—and the same applies in part to the basal ganglia—it is possible only to indicate a series of pictures to show the variation in different parts of the central nervous system and further to connect such variations in some general way with differentiation of function. Different methods of preparing and staining microscopic sections of the cortex, as well as of the cerebellum and basal ganglia, show different types and areas of cells. In the accompanying diagrams, observe first a section of the cortex taken from the motor area, and another, from the visual area. It will be seen that these are differently arranged in layers, with different groupings and forms of cell-bodies. On the same diagram is given also a different form of preparation which shows as well the minute cross-connections of fibres, which in this relation are also called axones, and the different types of cells. Here the star-shaped, or stellate cells characteristic of the visual area

appear. In the plate labelled "The Cortex of the Cerebrum" are shown in connection the four layers from the cortex downward, indicating once more the difference of appearance and distribution of the neurones and their projections. While these details are of great importance to the anatomist, they may be looked upon here as illustrating the variety of structure which is probably connected with some as yet obscure and minute difference of function. These several pictures may be interpreted as different views of terminal neurones, in turn forming parts of chains of neurones to and from the cortex of the brain, together with neurones serving as associational connections from one part of the cortex to another. Further details will be suggested in connection with the study of brain functions.

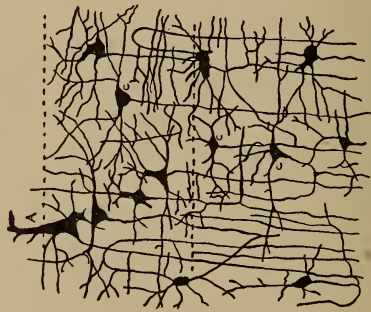
Topic XXXVIII. Functions of the Nervous System. Referring to James, pages 91 to 101, for the description of functions in the brain of the frog and of the pigeon, and of allied nervous structures in the higher animals, the following principles are emphasized: first, the purpose of the nervous system is to act as a center of correlation and coordination. The nervous system centralizes all the other systems of the body. The circulatory system, the respiratory system, the digestive system, the muscular system, the sensory system, all are in a sense represented in the nervous system. As a consequence the coordinate action of all parts of the bodily economy is provided for in their nervous connections. For example, in running along a given path the eye must hold the runner to a straight line; the legs must alternately support and advance the body, moving in rapid succession; the sensations from each step must be prop-



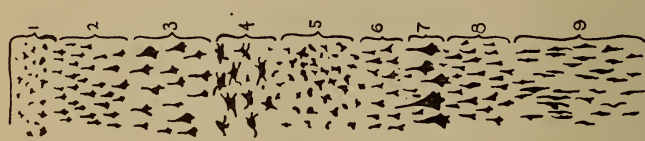
Motor cell in Spinal Cord



Spinal Cord



From the layer of stellate cells of the visual cortex



Section from the visual area



Section from the motor area

erly received and coordinated with the next forward movement; the lungs must accelerate their breathing to supply the necessary air; and with it the circulation and heart-beat must keep step. This centralizing agency is the nervous system. For the most part the study of conduct relates to the voluntary coordination for useful purposes of muscles, under the guidance of sense-organs. This coordination further involves the constant shifting of the combinations of muscles used in different occupations. Running and jumping and skating and walking and riding a bicycle all involve leg muscles, but in varied combinations. The nervous system thus represents in its complex connections provisions for the most manifold variety of combinations not alone in conduct, and specifically in those acquired coordinations which we call skillful movements, but as well in the accompanying adjustment of the other systems of the body. Likewise on the sensory side, digestion brings in sensory feelings of a vague, emotional nature, more conspicuous in their disturbance than in their normal function. Fatigue and recuperation, sleepiness and wakeful alertness similarly condition mental function.

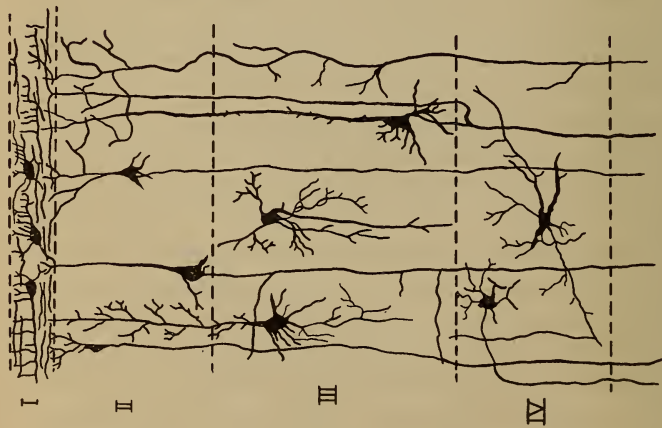
A further principle of importance is that suggested by the statement that the same muscles are repeatedly represented at different heights. This involves on the one hand that the higher center has no direct connection with the muscle. The higher center can but command or direct the lower center, which alone has an outlet to the muscle. Accordingly one cannot judge from the nature of a muscular reaction alone whether it is a high-grade action or a low-grade action. Winking may be purely reflex, and winking may be voluntary. The final distinction between the low-

grade and high-grade action is that the former is a direct response to sensory stimuli alone, involving slight or no consideration, while all types of higher action are indirect, or distinctly modified by consideration. Such consideration represents the complex field of memory, of forethought, of imagination, of thinking. It does this at least for our own high-grade actions. But even in the actions of lower animals, where these processes go on in much simpler form, something analogous enters to distinguish high-grade from low-grade actions. The recognition of a situation is the most common test; and the fact that the pigeon without its hemispheres will not recognize food or the call to which it responded when normal, indicates the parallel function of the higher centers in the pigeon and in man. The difference is the enormous difference of the extent and variety of the consideration that enters.

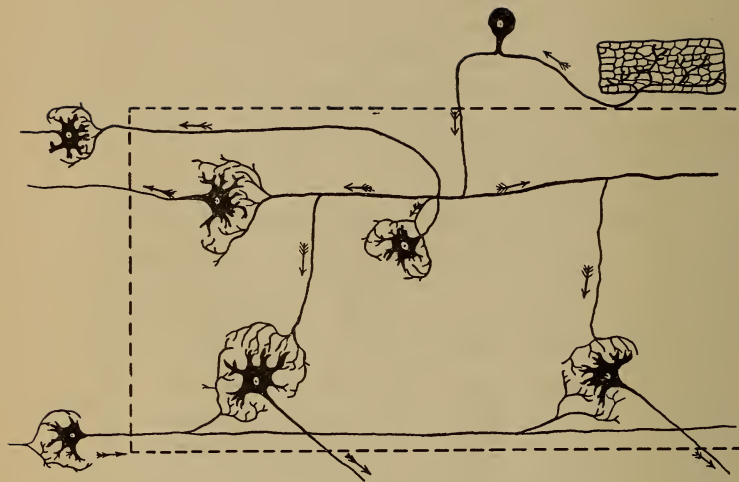
From the descriptions in the text it will be inferred that a very much larger share of the general behavior of the lower-type organisms is accomplished and provided for by their lower centers as compared with the similar conduct involving the higher centers; and that in turn the converse relation obtains in the human nervous system, where by far the larger share of function is of the higher type, leaving relatively little to the lower function except in cooperation with the higher. This brings about the frequent relation that actions which are ordinarily accompanied by slight consciousness and little volition may at any moment be drawn into the field of consciousness and directly regulated and controlled. A further consequence of this relation is that volitional acts as well as a goodly part of the reflexes and similar automatic actions of

man are acquired. They may be acquired, and very many of them are acquired, in early stages of infancy. Others are acquired, or at least perfected, at later periods. One of the most significant examples is that of walking, which is a coordination that requires in the child months, even years of practice before it becomes fully automatic and well performed, but eventually reaches so extreme a stage of automatism as to be carried on with the minimum attention and direction. It is characteristic that at any moment the higher centers may take the walking function under control. Thus in walking across a slippery or a muddy place, we instantly take charge of the walking process, attend to it and closely regulate it. Similarly the varied movements with knife, fork, and spoon in eating are the results of much practice and some deliberate training. We cultivate acceptable manipulations of this kind, and avoid those that are considered bad form. Such acquired mechanisms easily fall entirely into the field of habit, which as generally understood, means the consciously acquired actions which have become habitual.

Another principle of great importance is that of *inhibition*. The relation of higher to lower centers is not merely that of guiding, but also that of checking action. Control involves both. If in walking I slip and tend to fall, I automatically throw out my arm to keep or restore my balance. If, however, I am carrying in my arm a breakable and precious package, I will check or inhibit this tendency and save the package, even at the cost of injury to myself. So equally I may experience the reflex irritation which would be relieved by a cough, but I can restrain to some extent the actual coughing. Once more, in swallowing I de-



The cortex of the Cerebrum.



Path of conduction in Spinal Cord.

liberately bring the food to the point where the reflex swallowing mechanism will take care of it; but if in time I feel something objectionable in the food, I can still reverse and check the action. The inhibition or control of function forms a very large part of voluntary action; and restraint requires as much effort, and at times more effort than does the release of muscular contractions. This is due in part to the natural tendency for all stimuli to pass over into action. Thus when hearing lively marching music it takes more effort to restrain from beating time to it than to let the motor impulse find its natural outlet.

Topic XXXIX. The Analysis of Types of Conduct. While the distinction between lower and higher, or between reflex and voluntary action, is useful and the contrast definite, it is obvious that all manners and degrees of complexity of action exist between the two, with no sharp distinction at any stage of the series. Reflex actions are themselves more or less reflex, and involve different degrees and kinds of coordination. It is customary to use the word "automatic," and in particular, "primary automatic actions" to refer to a series of actions of the general reflex order, but which involves a larger degree of adjustment. Actions of a frequently repeated type which supply their own stimulus, such as breathing, form examples of primary automatic actions. Swallowing is intermediate in stage, the recurrent necessity of swallowing the saliva forming the repeated stimulus. So equally winking goes on in constant succession to clear the eye of any irritation; and these recurrent actions are more likely to be spoken of as automatic than as reflex, although the distinction in grade of nervous function is slight. Within the reflex field one may cite the pupillar reflex

as the most automatic, since it is present at birth, and needs no practice to make it perfect, is mechanical and specialized, enters into very little relation with other actions, has no feeling connected with it, and admits of no control. We may contrast with this winking, which is not innate but is a function that matures in the child at about the end of the third month, has a feeling connected with it, and may to some extent be controlled. Feeling is essential to control. We can only make voluntary such reflex actions as have connected with them some degree of feeling. The control of natural functions is part of voluntary training. The point is sufficiently illustrated in the more mature control of laughter or in checking the display of our emotions by expression, when the occasion makes it improper. The restraint of tears is another example. All this illustrates the variety of status which one or another action may have in the mental economy while yet its type is reflex or automatic.

The large group of actions called "secondary automatic actions" represent the field of *acquired reflexes*, or the general field of *habit*. Walking forms a conspicuous example, and, at first voluntary, soon becomes quite automatic. Even so highly complex and intellectual a process as talking may become so automatic that it will actually take place in sleep. Writing is a still more complicated and necessarily a voluntary and closely coordinated action, but its mechanical steps may become automatic. For example, in copying from a text the mind may wander while the pen keeps on and the eyes take in the words and letters, so that after a brief interval the writer is surprised to find that he has copied correctly, but with much reduced attention. The large field for the illustration of

habit is furnished by the acquired habits of manipulation with the hands, as in the several processes of dressing; or again manipulations of knife and fork in eating; in gesture and pose. These acquired habits always represent an individual factor, so that they are not quite the same in one person as in another. Many of these habits are acquired by imitation with very slight deliberate attention. Such action develops by easy stages into voluntary actions which always remain voluntary, though it incorporates automatic factors. Thus in speaking in public to an audience, the main attention goes to the thought of what is to be said, while the automatic shaping of the words proceeds.

A further relation in this function of the nervous system is the fact that actions best performed with large automatic control are not as well performed when deliberately and consciously carried out. Thus the difficulty that is sometimes experienced in swallowing a pill is due to the attention and effort directed to it. Swallowing goes on perfectly well automatically. So again in walking when we are made self-conscious, as in coming late at a concert or in church, the walking is unnatural, because not sufficiently automatic. It will be seen that the large range of function is voluntary and conscious, but is likely at any moment to shift in the degree of control or consciousness accompanying it, or again in the measure to which automatic habitual reactions participate in the result.

It is hardly possible to interpret all these relations in terms of the nervous system, but it is useful to conceive of the nervous system as providing in its complexity of relations for these varieties of conduct regu-

lation. Were conduct not of such several varieties and degrees of complexity, were the correlations not so vast in number and so variable, the structure of the nervous system, though composed of similarly constituted units of function, would be adequate on a much simpler basis,—fewer specialized divisions, lesser complexity of combination, more limited interplay of parts.

Topic XL. The Higher and Highest Cerebral Functions. The cortex of the brain represents the highest type of centers, and their action represents the most developed and complex function of the nervous system. The cortex participates in a great range of conduct, often supplying merely the directive or coordinating factor and more typically raising the action through the associations which are aroused into a complicated mental act. The nature of these mental accompaniments, which for the present may be indicated by such a term as *consideration* or *association*, or again *memory* as reflecting past experience, and *prudence* as anticipating future results, will be duly considered in later topics. The present purpose is to gain a picture of the processes that accompany relatively simple actions of the voluntary and considerate type. At the simplest the movement of an infant's hand towards a bright light is illustrative. The sensory stimulus from the eye must excite the terminal organs, which now we may picture as the expansions of a sensory neurone, must travel along to a point in the brain-stem which represents the end of this first neurone. (So much of the path is formed by a group of fibres in the optic nerve.) From here the impulse passes to a second link in the neurone-chain and travels upwards and backwards until it reaches the

visual center in the occipital region of the cortex. From here in turn the impulse radiates through connections already established between these centers of visual reception and the centers of motor control; and in this group of cells lie those particular motor cells which represent the movements of the hand; the outgoing impulse travels downward until it reaches the end of this central motor neurone, which in turn passes over the impulse to the terminal motor neurone, which has its origin in the large cells of the anterior horn of the spinal cord at the level between the shoulder-blades, and from here travels along what we should now call a motor nerve, and releases by a special type of contraction the combination of muscles which we call the movement of approaching or grasping. When, however, the result of placing the hand near the flame is pain, instantly another process similar to the former is set up, must again travel to the brain and back to the spinal cord, and reverse the movement, which is represented by the withdrawal of the hand. It is thus clear that even the simplest action involves a large nervous connection, and its detailed description would be almost endless. The physiologist's problem is to trace the assignment of paths in the nervous system to these several varieties of action and connections. If we contrast with grasping the indefinitely more complex act of reading, it will be seen that the general description is the same, but that the chief difference is in the endless complications within the cortex, the associations in terms of memory and meaning which the visual symbol that we call a word arouses.

In such illustrations the essential point is to select the relations which are typical and characteristic.

These may be regarded as lying primarily within the associations of the cortical centers. Such associations must be formed by experience, and their establishment represents the education of the nervous system. The difference between one act and another lies primarily in the scheme of associations which it involves. Such a scheme always involves presentative elements, which are in terms of actual sensation, and representative elements, in terms of meaning associated with them. Thus the act of reading involves the seeing of the page of letters, which is the presentative element, but distinctively the recollection of the meaning associated with the form. One sees a page of Chinese as clearly as a page of English; but the Chinese is purely presentative and represents so much visual form, while in the page of English the form is but slightly attended to, the attention going at once to the meaning. While we cannot point out in detail what may correspond to this important difference in the nervous system, we feel warranted in regarding it as the highest form of cortical function on its sensory side. Coordinate with this is the highest form of function on the motor side, which represents at once the control of the lower centers, as already illustrated, and the effort of bringing into relation the accumulated associations which we call thinking. Thinking, or the assemblage of useful and controlled associations, is as much effort as is doing. As in all the receptive processes, there is the strong sensory or presentative element, so in all motor processes there is the resulting action or coordination of muscles. When this represents the chief factor, as in manipulations of great skill, the operation is more motor than mental, though in every case it is both. Thus in watching a juggler keeping many balls in the

air, or balancing combinations of delicately arranged objects, we look upon the accomplishment as largely one of manual skill under visual and kinesthetic guidance; yet this, as do all games of skill, requires headwork as well as handwork. When, however, we analyze the act of writing, we recognize that the manual expression has become largely automatic and that the operation is largely mental; the attention is to what is written rather than to the strokes which shape the letters. Combining these two principles we realize that the function of the highest centers is to *get meaning out of sensory responses* and to *put meaning into motor contractions*. It is this "meaning" element that forms the subject of many of the remaining chapters of psychology.

It must now be shown that the presence or absence of this element of meaning has a representation within the nervous system. It must be shown that the sensory factor may persist while its interpretation falls away, or again on the motor side that the contraction of muscles goes on without forming significant conduct. This consequence results from the conception of the highest type of function as that of purposeful deliberation as well as considerate conduct. The best evidence is that from mental blindness, both in animals and in man. This is a condition in which the eyes see, so that the animal does not blindly walk into an obstacle but goes around it, but in which the object is not recognized—is reacted to indifferently as an object or obstacle quite irrespective of its nature. This is inferred from the fact that the object does not excite its normal response. Similarly there may be no paralysis, but an inability to perform acquired conduct owing to the falling away of the correlating

control. This has been shown for dogs that have been taught tricks. Such dogs, when certain portions of the cortex have been removed, will continue to perform simple operations but can no longer coordinate the movements of the acquired tricks. For man these illustrations are best observed in the defects of speech, for which see the text.

We thus reach the conception that the functions of the cortex must all be capable of expression as states of sensory reception or of motor expression. The only arrangements which the brain stands for are these two; of sensory interpretation and motor expression. All that we know and all that we do is capable of description in these terms. The nervous system as such represents complex arrangements for sensory reception and motor coordination. However, the enormous importance of the connection between reception and expression gives to the process of re-direction the largest place in our psychology. While we cannot describe the mental content of these associative steps in any helpful terms of the nervous system, it remains important to hold in mind that they are bound up with nervous processes. Such examples as reading, writing, speaking, copying, and even the more complex language processes like translating, are after all expressible in terms of sensory and motor operations, together with the associations directing them. Furthermore the degree of specialization within the cortex represents the uses to which we have put our sensory and motor centers. The visual center represents the general portion of the brain at which the impressions from the retina are received and interpreted; and if we come to develop a reading center, this in turn is but a specialized part of the visual

center,—specialized for the interpretation of this acquired visual distinction. Similarly a certain portion of the motor area represents the center for the issuing of impulses to the general region of the face and vocal cords; and if we have developed a speaking center, this means that a special grouping of this motor center specifically operates those coordinations of voice and tongue, etc., which result in speaking. It is well to think of the specialization of the brain in terms of acquired coordinations and interpretations.

CHAPTER VIII.

REACTION-TIMES.

Topic XLI. **Reactions.** Conduct may be thought of as composed of bits of conduct, each one of which conforms to the type of a reaction. The simplest reaction includes the response to a stimulus, but involves something above a reflex. It involves that the response is arranged, and thus is the simplest type of voluntary action. If, accordingly, I wink the eye as quickly as I can I after hear a certain sound, it represents the minimum time for a *simple* reaction. The average of such time is about $1/7$ of a second. If, on the other hand, the winking reflex takes place in response to an actual sound or flash, it may be much quicker than this, even as short as $1/20$ of a second. In cases of explosion of a glass beaker in a chemical laboratory the chemist has often escaped without injury to the eyes, but with fragments of glass imbedded in the eyelids. It is safe to assume that if the eye had to be voluntarily closed, the glass would have had time to enter the eyeball, but the reflex closure was quick enough to prevent it. We may thus define a simple reaction as a response by a predesignated movement that an expected stimulus has been received. Such simple reactions hardly occur in the natural course of employments. A near approach to them, where a fraction of a second is important, is the starting of runners for a hundred-yard dash. In that case the sound of the pistol is the stimulus, and the getting off

the reaction. Even a slight gain in promptly getting under way would be of advantage. Photographs have been obtained which show the smoke leaving the pistol, while yet no runner has left the mark. The photograph was instantaneous, requiring 1-40 to 1-20 of a second, which is less than the time needed for even the quickest runner to start.

Simple reactions are important because they set the limit of all possible reactions. Every more complex bit of conduct includes the simpler. The simple reaction, in turn is conditioned by the rate of impulse in the nervous system, which is about one hundred feet per second. We may divide the complete reaction-time into the part occupied by the ingoing impulse, by the central redirection, and by the outgoing impulse. The largest part is consumed by the redirection. We do not know the nature of this process, but have many indications of its complexity. We accordingly reach the formula for the *adaptive* reaction that it includes a simple reaction plus other factors. These other factors are easily shown to be *distinction* and *choice*. If, instead of making the uniform response to the single signal, the signal may be one of two or more, and I select the response according to the stimulus, I have the formula for an adaptive reaction. As demonstrated in class, to touch one's neighbor as soon as you receive a touch on the hand is a simple reaction. To expect a touch either on the thumb or on the body of the hand, and touch your neighbor at the same point, is an adaptive reaction. If, in addition you must touch the same finger as the one upon which you were touched, it is a more complex adaptive reaction, involving one of five distinctions and one of five choices. By subtracting the simple reaction-time from

the total time necessary for these reactions, one may ascertain the mental time required for distinction and choice. Distinctions and choice are intimately related, and are bound together by association. It is this association that must be established and which when established we form a habit or memory.

While all bits of conduct are adaptive, these adaptive reactions vary enormously in complexity. Complexity is due not only to the *number* of distinctions and choices, but mainly to their *nature*. Complexity in distinction involves less addition in time than complexity or number of choices. A larger part of the additional time in making a reaction to five stimuli above what is needed for two, is due to the motor complexity—the choice—than to the distinction. Similarity in learning to use a typewriter rapidly, the training is in large part on the motor side. If we take as a complex example the sorting of the outgoing mail in the postoffice, the process is complex because the clerk has to distinguish a large number of addresses; he must associate a large number of towns each with its own mail route; he must further associate the mail-route with the particular pouch in its position as it hangs as one of the very many in a semi-circular rack; he must finally have skill enough to toss the letter accurately into the proper pouch. This reaction shows each factor of the complication: the original learning of the mail routes, the memory-association of towns with the route, the habit association of the town with the mail pouch, and the skill or motor facility in directing the letter accurately to its place. None the less, as we compare this reaction with other complex ones, we observe degrees of complexity in the associational process. Here lies true mental difficulty. The

type of association may vary almost indefinitely. A special type of association is that which involves thinking, reasoning, judgment, comparison, etc.

Topic XLII. **Association-Time.** While associations as conditioning conduct and thinking deserve and will receive special consideration, the study of association-times belongs in this connection. When a reaction is distinctive by reason of the association it involves, it is called an association-time. The association is in this sense the completing process of the reaction, and the readiness of associations in some sense determines the availability of knowledge. A large number of mental processes standing for associations may thus be measured. For example, if I require a subject to repeat words as promptly as possible after me, I may call his average time in so doing *repetition-time*; if I give him the task of translating these simple words into German or French, the additional time would stand for the time of associating the English with the foreign. It is clear that associations have a direction. It would take an English-speaking person less time to give the English of a German word than the German of an English word. Thus familiarity is measured by the readiness with which the knowledge that in some sense we have, becomes available. I might further measure the time necessary to *name* colors, or to name pictures, or to name geometrical forms. This is something more than recognition. I must both recognize the form and arouse the association of its name. It is when the name association is very intimate that it seems to merge with recognition. The study of such recognition-times and naming-times indicates the original separateness of the processes. While the study of

these times has been very extensive, these illustrations will suffice to show the principles involved.

All such associations are in a manner fixed. In learning the multiplication table we learn to associate 63 with 7 multiplied by 9. Much of our geographical knowledge is in terms of fixed memory-association. We associate London with the Thames, Paris with the Seine, New York with the Hudson. As we move away from fixed associations, we move towards free associations. A considerable interest attaches to unlimited associations. The type of these is that of the measure of time necessary for one idea to call up another. Thus if the words *book*, *horse*, *tree*, be suddenly spoken, and the subject asked to give the first word or idea called up by them, the intervening time is called a free association-time. It varies considerably, but for simple terms and ready associations is about 3-4 of a second. Postponing further consideration of associations, attention is directed here merely to the place of association in conduct and in preparing the knowledge on the basis of which reactions take place.

Topic XLIII. **Habit and Conduct.** Referring to Chapter X for the main points in regard to the nature and workings of habit, it remains only to bring the processes of habit in relation to reactions and conduct and to indicate what changes habit introduce into these relations. We may consider conduct as composed of a series of reactions. Certain types of reactions, by being done over and over again, are reduced in status; actions at first voluntary become second nature by habit. It is this large range of acquired habits that conditions mental work, and conduct alike.

The practical effect of habit may be summed up by saying that habit makes reactions easy; habit makes accurate; habit makes quick; habit makes regular, and habit makes proficient. The subjective accompaniment is that actions are done with diminished attention and this induces the sense of ease. Objectively the gain in quickness is due to the close-knit associations between one step and another, as well as to the elimination of irrelevant movements. The precision is a gain in muscular control, which is again the elimination of the unnecessary, as well as a clear-cut conception of processes. Regularity is but another evidence of the same change. It is in proficiency that the main utility is summed up. When this is further analyzed it is probably due in the main to overlapping or telescoping of the several processes. While a process is new, each step must be done separately, and the total time is almost the sum of the times of the individual steps. Facilitation enables the attention to spread over a large unit, to initiate the next step before the one is disposed of; and in this condensation the large gain in proficiency lies.

CHAPTER IX.

ATTENTION AND MENTAL ELABORATION.

Topic XLIV. General Analysis of Mental Procedure. For the remaining part of the course we have to consider the general elements of the process of elaboration, the complex set of changes that happens to the material which is the foodstuff of the mind before it is transformed into the direction of conduct. In general we call this thinking; but it is easy to detect the common processes involved, and to give them a separate standing. The most general of these processes is attention; for attention represents the condition of mental effort. Next come a group of processes which may be called memory, perception, association, imagination, and reasoning. Thought consists in the orderly use of these processes in behalf of a unified interest. The phases of this problem, which alone we shall be able to consider, will then consist in setting forth the principles determining the chief relations in terms of function of attention and the other processes mentioned. Viewed for the moment as a whole, they represent the reaction to absent stimuli, to situations in the past, and direct conduct towards the future. We think because we do not live merely in the present, but require for the regulation of life the consideration of present stimulation in terms of past experience and of future anticipation.

Topic XLV. Attention. Chapter XIII gives the main facts in regard to the working of the attention

and to the account there given need be added only certain general applications and emphasis of principles. Let it be observed first, that attention is *selective*; that it determines which of the many invitations to interest or conduct shall be in a favored position for acceptance. Attention on its receptive side thus selects the particular stimuli which shall enter the field of consciousness. Within this field it further selects by giving emphasis to some phases or parts of a situation as above others. The more special problems relate to the mode of action of the attention. First may be considered its source and the mode of its maintenance. Here the classic distinction is that of voluntary and involuntary; while in general distinct, the one merges into the other. So long as stimulations have a natural interest, the attention goes out to them without effort. While the acquired interests represent effort and control, once established, work under acquired interests goes on more and more along the pattern of the involuntary type. The sense of effort diminishes with familiarity and facility. The more important distinction relates to the spread of attention as concentrated and dispersed. Here a double distinction is involved, namely, the amount of available energy, and secondly the direction or spread in which that energy is expended. Thus fatigue is the most general physiological condition of attention, and there is no more sensitive index of mental fatigue than the wandering of the attention. One may picture the distinction as that between illuminating a field, whether narrow or broad, with a low illumination, or illuminating it with a high illumination. The confusion should be avoided between a change in the general amount of illumination and the distribution of that

illumination. It is the latter sense that more specially attaches to the distinction between concentrated and dispersed. Dispersed attention may be eager and vivid, but is not allowed to play over a large field. It is true that concentration and energy usually go together; but the mere confining of the attention to a narrow area often eases the task. It is the necessity of attending to a large number of possible relations that makes a task difficult. A concrete illustration will help. When an author reads proof, he puts a great deal of attention upon it and critically revises any slips or imperfections of style, phrasing, diction, syntax, grammar, as well as maintaining a general look-out for at least serious misprints. The task demands concentration in the sense of energy, but a dispersed attention in the sense that that energy is expended over a large number of separate relations. On the other hand, the proof-reader has an easier task because he is not reading for sense, but for appearance only; though he, too, will detect glaring mistakes in grammar or phrase at the same time that his eye and mind are set for the narrower interest of the print. In the end the distinction is largely that of maintaining a *consistent* attention which, in turn, may be concentrated or dispersed. Going back to concentration in the earlier sense, the main practical problem is the elimination of distraction. There are ever apt to be rivals for attention. The rivalry is often between an acquired and a natural interest—between holding the mind by force to a narrow line of thought, while yet other occupations are more inviting. The ability to hold the mind to a task by effort should not be confused with, though it is related to, the distribution of attention within a given task. The latter brings us

back to the problem of habit and attention, which indicates that that number of things that may be attended to at the same time, provided that they are related to a common end, is really a measure of mental proficiency. For remaining points see Chapter XIII.

CHAPTER X.

PERCEPTION.

Topic XLVI. **Perception.** Referring to the chapter on Perception for the statement of the relation of perception and sensation, the nature of sense-illusions, (including the two types and the definition of apperception), a few main considerations of the perceptive processes in mental elaboration will be considered. In general, perception is the process that makes of vague or indeterminate somethings concrete definite things. It breaks up great masses of mere stimuli into definite arrangements and systems of objects. Naturally this includes recognition. Recognition is in terms of meaning acquired by past experience. The sensory element persists in perception, and in all but its highest stages remains prominent. It becomes necessary to distinguish between sense-perceptions with a *strong sensory* factor, and those in which the *perceptual* factor gradually *increases* in significance. The two always merge; but the principle remains that as the sensory element recedes, the perceptual element advances. The one is strong as the other is weak.

Perception interprets sensation, or better, it interprets groups of sensory stimuli. It makes unitary objects out of composite appeals to sense. Thus the perception of a bell combines the sound, the shape, the use, the material, all of which are not bare sense-stimuli, but result from them. Particularly does perception proceed on the basis of meaning; stimuli are

no longer mere impressions, but composites of meaning. In the end, interpretation gives way to inference,—which is but a more highly specialized form of interpretation in which the steps are either a little farther apart, or involve a logical quality. There is very little difference between anticipation and inference; but the difference emphasizes a stronger sensory factor, in the former, and a logical one in the latter. Thus, in the end, objects are inferred from individual signs. Sensations become the signs for calling to mind perceptions in terms of revived experience.

Illusions contribute apt illustrations of these distinctions. They are perceptions that are incorrect in terms either of more critical perceptions or of judgment or of reason. The first order of illusions is entirely objective, that is, it presents an arrangement of stimuli in which the seeming appearance is not that which by a critical judgment may be shown to be the actual arrangement. Such illusions may be called objective, in the sense that the construction of the object determines the illusion. Nothing is required, or very little, to be added by the mind. Yet such illusions are composite, and may contain stronger sensory or more largely inferential elements. Of the variety of distortions of lines and figures shown, it may be said that most of them are strongly sensory, and that the ones that illustrate perceptual elements do so by including more complex experience. It is a partial test, to be applied cautiously, that illusions that are most marked at the *first* impression are strongly *sensory*, and grow less distinct as they are viewed critically, while illusions depending largely upon inferential elements grow rather *stronger* the more closely they are attended to. The main dis-

tion brings in the second type of illusion: the proof-reader's illusion—the mistaking of an object by means of anticipation. Thus when expecting a carriage, one converts any kind of a noise into the rumbling of wheels. Further illustrations are given in the text. They show once more that a perception starts with a sense-stimulus, but is completed from within. It is when the sensory sign is mistakenly completed that we call it an illusion. The working of perception is evident, whether correct or incorrect.

CHAPTER XI.

IMAGINATION.

Topic XLVII. **Imagination.** Again referring to the chapter on Imagination for details, it will be possible to further emphasize a few general relations. The terms *imagery* and *imagination* are often used in confusing, even in opposite senses. The main fact emphasized by the word *imagery* is the vivid persistence of the sense element in the revival of past experience. We think of the past only in so far as the memory-images remain; and these are primarily sensory in form. Thus images of color and form in the visual field, of sound, or of movement, form the real basis of revival. This is best shown in terms of the dependence of different individuals upon different types of imagery. The eye-minded person is strongly attached to visual images; the ear-minded person to auditory ones; and the motor-mindedness, while largely a support through feelings of motion, contributes essentially to the composite process. Illustrations in the text are adequate. Observe that these show not merely a large range in accuracy, in definiteness, and in scope of the visual image amongst different individuals, but also different degrees of dependence upon visual, auditory, or combined types of image. In general, the imaginative person, in the sense of a person with a good visual or other imagery, is one who can readily reconstruct a scene, making it in imagination approximate the

actual. (Here, again, see illustrations in the account of Galton's inquiry.) The use of such a phrase as the *creative* imagination suggests that in the absence of concrete and rich imagery, it is the imagination that must help out. Creative imagination thus suggests the very freedom from literal sense-images, but also the power to recombine vividly the elements of experience. Vivid imagery and vivid imagination may and are apt to go together. The vivid revival of actual experience suggests equally the quality of vivid reconstructions from combinations that have not entered into experience. None the less, the relations between the two is by no means necessary, since the element of novelty is particularly emphasized by the term *creative*. The simplest combinations are those represented in ancient mythology, where a Centaur is combined of the body of a horse and the head of a man; a mermaid is half woman, half fish, etc.; elements of real experience are differently combined. Nothing is absolutely novel, but the remoteness from experience increases as the creative imagination works upon its material. The creative imagination is not limited to literary features. There is a scientific imagination which similarly gets away from the literal, anticipates facts, constructs relations that are possible, conjectural, rather than actual. Thus the larger sense of the word is justified in that it represents the power to perceive the absent, either constructively or pictorially. The architect exercises imagination in creating in his mind the building which he then reduces to drawings; similarly the ability to see the building from the drawings is an example of the power of imagery. In a negative way, the same principle is illustrated

by the difficulty of *imagining things away*, of realizing how a house would look if it were altered. The power *not* to see what is present is similar to the power to see in the mind what is absent. Observe, lastly, that the second type of illusion, in which we misconstrue or faultily perceive, is due to the exercise of the imagination. It is again the subjective element which is contributed by the imagination to perception, that forms the largest type of serious illusions. In the end these may become true hallucinations. (This topic is touched upon in the closing parts of the chapter on perception.)

CHAPTER XII.

ASSOCIATION.

Topic XLVIII. **Association.** (The aspects of the problem of association which will now be touched upon in these notes is intended to supplement the points given in the text. For the most part points there given will not be resumed. Also observe that to correctly understand this section it may be desirable to read first the lecture notes on *Memory*, which will be given in the next and concluding section.) The particular problem of association represents that phase of function of mental elaboration through which and by which thought advances. It represents the system of connections between ideas, and again between perception which arouses ideas, and the meanings contained in them. Association in terms of experience represents the simplest side of this subject. This has often been too closely regarded. The older principles brought forward as types of explanatory association, association by familiarity and by contiguity, either mean too much or are very partial explanations. Mere contiguity, either in time or space, is a very limited type of association, for it is the very business of association to separate things that come together and put them where they belong. Association sorts experience into systematic groups, and is not dependent upon mere contiguity. Likewise, similarity does not indicate the true basis of association,

which would be determined by the type or quality of similarity in which the succession lies. This distinction at once suggests that association moves in terms of meaning rather than of original experience—of *mental* situations and similarities rather than *material* situations. Thus one of the most significant distinctions relates to association as *logical* and as *objective*, as determined by sequence in experience or in pictures, or by sequence in logical thought.

An essential characteristic of association is its uncontrollable quality. We attempt to call upon associational steps, but in the end they depend upon happy circumstances. Given a theme and the task of expressing one's ideas, it still remains uncertain, because of the uncertainty of the flow of association, what the outcome will be. The preparation of a preliminary outline is not merely an aid to memory, but assures the flow of thought in a given direction. It assures stopping-places from which new associations may be developed. If the preparation of the paper be interrupted, we are convinced that, when resumed, it will not continue precisely as though further progress had been made at the first sitting. We can never quite go over again or command the same associations; yet the development of thought will be similar. These minor variations, while significant, yet do not detract from the greater significance of the acquired habits of association which stamp our individual thinking and make it characteristic. The best we can do to control associations is to set the mind thinking along lines of interest; to gather material, which means making the data accessible; and with increasing familiarity to concentrate directive efforts upon the task. We cannot expect associations to come

without that effort of attention which, as it were, makes accessible in the outlying regions of thought, those clusters of ideas which next become available when relations are seen and associations are established.

Association is thus considered largely on the side of thought. It is equally clear that it has an important bearing upon sense-experience and upon habit. These bearings, however, are much simpler, and are directed to the explanation of the problems why and how elements of experience are joined, how and why sequences of behavior are more or less automatically established. These topics are sufficiently covered under *Habit*, and will appear again in the section on *Memory*.

CHAPTER XIII.

MEMORY.

Topic XLVIII. **Memory.** Memory in general is the recalling of previous impressions or experiences and referring them to one's past history. For a more complete definition and its essential elements consult the text, Chapter XVIII.

An important distinction that needs to be specially emphasized is the relation between recollection and recognition. Many impressions are revived with a feeling of familiarity unaccompanied by minute details as to time, place, and circumstances of the original experience. Other impressions are revived in complete detail accompanied by accurate location in time and place. The former is recognition, and consists in the identification of an impression or object when that impression or object is presented again. The latter is recollection and takes place without the aid of the original stimulus. Obviously our range of recognition is very much larger than our range of recollection. We are able to recognize a great many more things than we are able to recall. In the second reading of a book one is able to recognize a great many incidents as having met with them in the first reading, but one would be able to recall voluntarily only a small percentage of the facts that can be recognized.

Memory may be classified on the basis of the logical arrangement of the memory contents as desultory or

systematic; or on the basis of the images employed in the recalling of the impressions, as visual, auditory, motor, etc. For details consult the section on the Imagination.

Another important problem is, What determines the order or succession in which ideas return in memory? Quite a number of factors and principles enter into this problem. Four of the more important factors which determine the course of associations are primacy, recency, frequency, and vividness. Stated simply, these principles are that, other things being equal, the first impression or event (primacy) in a series of events, or the last impression (recency), or a repeated one (frequency), or an unusually vivid one (vividness) in a series of items is more apt to be recalled. For a more detailed statement consult the text, page 267.

Physiologically the basis of memory is the same as the basis of habit. Impressions once made leave a more or less permanent effect or change in the nervous system. A good memory depends therefore partly upon the native retentiveness of the nervous system, partly upon the number of brain paths or associations and partly upon the persistence of the associations.

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